Air Quality Observation Systems in the United States

Draft Report

Prepared for review by
Committee on Environment and Natural Resources (CENR)
Air Quality Research Subcommittee (AQRS)

January 2010

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Executive Summary – Air Quality Observation Systems in the United States

Air quality observations are an irreplaceable source of information needed to effectively develop and implement public policy to protect public health and the environment. Several hundred million dollars are allocated annually by a number of federal agencies, together with state and local partners, to maintain and operate the nation's fixed monitoring networks, short-term field studies, and satellite remote sensors. However, the full value of data from these efforts is not realized. Each type of observation has inherent limitations. Institutional barriers and resource limitations currently impede our ability to maintain observational capacity, synthesize observations of various types and from different agencies, and adapt current systems to meet observational needs as our understanding of air quality improves and the atmosphere changes.

The value of air quality observations can be enhanced by coordinating the planning and operations among federal agencies, which often have compatible monitoring requirements. Coordination of measurements also facilitates intercomparison of data, allowing limitations inherent in data types to be addressed and more value to be realized from observations. We recommend creation of a multi-agency Working Group authorized (and with adequate new resources) to identify measurement gaps to be addressed by member agencies. The Working Group would also focus on making monitoring data more available, interoperable, and usable, and on adapting observation systems to emerging issues.

This report catalogs a variety of air quality measurement programs, including routine regulatory and deposition networks, intensive field studies, satellites, and fixed-site special purpose networks. Based on an analysis of these programs, this executive summary enumerates observational needs and issues, opportunities, and barriers to positioning monitoring programs to assess current and emerging air quality issues. Recommendations are made to senior managers and resource decision makers at federal agencies engaged in air monitoring programs (e.g., EPA, NOAA, NASA, USDA, DOE, DOI) and associated state, local and tribal partners.

ES.1. Observational Needs and Issues

1. With the success of local and regional emission reduction efforts, distant/international pollution and natural sources have greater relative impact on air quality. These are not well characterized by existing observation systems.
2. Some air pollution health effects are likely much greater near certain sources, such as major roadways, while routine air quality monitoring is typically conducted at fixed sites further away from these sources.
3. Our understanding of atmospheric and deposition processes and emissions budgets is insufficient to allow models alone to guide many important air quality decisions.
4. Satellite remote sensing observations have unique value and inherent limitations. They particularly require intercomparison with fixed-network and short-term field observations and models.
5. Coordinated atmospheric, deposition, and effects monitoring is needed to understand deposition impacts on aquatic and terrestrial ecosystems.
6. Global climate change will affect pollution emissions and atmospheric processing; observation systems must document and adapt to these changes.

7. Observation programs need to be developed to track the progress of future emissions management programs for climate forcing pollutants.
8. Insufficient attention is given to precursors of ozone and particulate matter, which must be monitored to assess emissions control strategies.
9. Air quality models and forecasts rely on measurements for improvements in initial and boundary conditions, and for evaluation.

ES.2. Opportunities

1. Satellite remote sensing of air quality and emissions is rapidly maturing in its capability to augment and extend the spatial and temporal coverage of fixed-site monitoring networks and short-term special studies.
2. Air quality models are able to augment observations with credible spatial, temporal, and compositional information lacking in the measurements.
3. Enhanced access to observations, metadata, and processing tools provides an efficient mechanism to harmonize data from disparate measurements and assessment programs and data of various types.

ES.3. Barriers to Progress

1. Federal budgeting practices do not adequately address long-term maintenance and updating of observational infrastructure.
2. Agencies often support their own priority programs at the expense of joint efforts that have significant national interest. For example, very few data are available to characterize the increasing concentrations of pollutants transported across the Pacific.
3. Use of data from advanced technologies, including satellites, is limited by inadequate resources for transferring data and tools for data manipulation.
4. Weak market incentives inhibit the commercialization of advanced methods in the absence of a government mandate of the method.

ES.4. Recommendations

1. Establish a standing multi-agency observations task force that reports to senior managers and/or resource decision makers, and

    a. conducts periodic adequacy reviews of the nation’s observational capabilities,
    b. identifies gaps and overlaps among programs,
    c. builds cooperation and coordination among government programs,
    d. establishes minimum standards for program design/implementation,
    e. promotes the use of common data formats and communications protocols,
    f. identifies opportunities for development of, and reviews / recommends use of, new observational technology.

    This task force would operate as a Working Group of the AQRS.

2. Address current observational gaps that require action in part to:

    a. initiate monitoring of reactive gas and particulate nitrogen compounds, which are precursors of ozone and particulate matter, contributors to acid deposition, and nutrients in ecosystems,
    b. collocate instrumentation at core measurement sites to facilitate inter-comparison with satellite observations,
    c. expand observations in rural/remote areas to measure regional backgrounds and contributions from long-range transport of pollutants,
    d. establish monitoring in near-source areas to track trends and better understand observed near-source health effects, and
    e. expand intensive field studies designed to elucidate critical processes that determine atmospheric concentrations of ozone and particulate matter and other air pollutants.

1 Introduction

Observations of air pollutants in the troposphere, such as ozone, particulate matter, and their precursors, together with meteorological conditions and other physical parameters, are essential to our understanding of air pollution and are key inputs to a variety of assessments supporting environmental decision-making. These include studies of the effects of air pollution on human health, ecosystems, and agriculture, assessments of air quality management strategies and policies, and work to understand the chemical state of the atmosphere, for example to study the links between air quality and climate. The high financial stakes surrounding air quality management also necessitate thorough observations of atmospheric composition, given that the costs and benefits associated with Clean Air Act requirements are estimated to be on the order of tens of billions of dollars per year (NRC, 2004). Because of these diverse needs, a variety of federal agencies and organizations make, process, and use these observations. These agencies share common information needs. Opportunities exist to increase the value of air quality observations by integrating them across environmental media, pollutant categories, and spatial scales.

Decision-making with air quality observations also faces a number of current and emerging challenges, such as the need to assess the effects of pollutants in the context of other pollutants, as they cross between environmental media, at various spatial scales, and in a changing climate. Air quality monitoring systems are also challenged by the need to establish scientifically defensible baseline concentrations and to track environmental response to expected major energy and environmental policy shifts. Against this backdrop of demands on air quality observation systems are an array of resource, technological and institutional barriers which impede the maintenance, evolution, and integration of measurement networks within and outside North America.

The value of air quality observations can be enhanced by coordinating the planning and shared operations among federal agencies, which often have compatible observational requirements. Coordination of measurements also facilitates intercomparison of data, allowing limitations inherent in data types to be addressed and more value to be realized from observations. This report on observations of air quality is intended to (1) describe the basic content (i.e., measurement parameters, locations, sponsoring organizations) of ambient monitoring and other air quality observations, mostly in the United States; (2) identify gaps and opportunities to enhance the value of these measurement programs through inter-agency cooperation and collaboration; and (3) advocate for sustaining and improving our nation's observation systems. Such improvements in our ability to make and utilize ambient measurements are thematically consistent with recommendations by the National Research Council (NRC, 2004) on improving air quality management practices. The targeted audience is extremely broad and includes policy and decision makers as well as a broad technical community of academic, private sector and government researchers and technical staff engaged in environmental assessment. To communicate to this diverse audience, this summary report expands the discussions on issues and recommendations, while the appendices provide a more comprehensive inventory of monitoring networks and observation programs.

1.1 Current and Emerging Air Quality Assessment Challenges

Over the last two decades, air quality management in the United States has focused on regional scale air pollutants such as ozone, particulate matter, and acid deposition, all of which remain issues of concern for the foreseeable future, especially if air quality standards continue to tighten. Traditional management strategies typically take an independent, specific approach to target monitoring. In contrast, emerging challenges in air quality management are influenced by an assortment of factors requiring a more comprehensive and well-integrated assessment framework:

- Multiple pollutants – Several pollutants are emitted by common emission sources, and participate in similar atmospheric chemical and physical transformation and loss processes. As a result, populations are often exposed to multiple pollutants. Our current air quality standards and air quality management framework, based on the Clean Air Act, are single pollutant programs. Air quality management is attempting to move to a multiple pollutant approach, but measurement systems are currently structured to support single-pollutant assessments.
- Multiple environmental media – The atmosphere is closely coupled with terrestrial and aquatic systems. These systems are major sinks for air pollutants, leading to effects on ecosystems from acids, nutrients, and toxics. In turn, soils, vegetation, and aquatic systems re-emit mercury and persistent organic pollutants (POPs), and meteorology and climate affect biogenic and biomass burning emissions. These linkages require a broader perspective on environmental monitoring, which traditionally addresses issues on an isolated media basis. Monitoring coordinated across media will be required to assess progress mitigating the effects of atmospheric pollution on human health, ecosystems, and agriculture.
- Multiple spatial scales – Long-range (inter-regional and intercontinental) pollutant transport is becoming important as local emissions are reduced and transport across U.S borders increases, reflecting expanded world development. Meanwhile, concern is growing about the near source/roadway environment, where a majority of the North American population lives, exposure is high, and the chemical environment is dynamic and poorly understood. These scale issues, at opposite ends of the spatial spectrum, challenge the current assessment framework that emphasizes regional air quality management.
- Climate-air quality interactions – The bi-directional interaction between air quality and climate change will be increasingly important for air quality management. A variety of emissions, atmospheric chemistry, and transport processes that affect air quality are modified by climate change. Conversely, several air pollutants, particularly ozone and particulate matter, are significant climate forcers, and air quality changes impact atmospheric and emissions processes, impacting climate. Moreover, climate forcers and conventional air pollutants are largely emitted from common sources. Consequently, emerging energy policies designed for moderating climate and policies designed to improve air quality are intrinsically connected, and measurement system design should account for this link.

Moving forward, air quality observations systems will need to provide the data needed to assess progress in light of these emerging challenges. A wide range of observations will be essential for this work. Observation strategies should enable detection of expected modifications in atmospheric chemistry brought on by changing technologies and fuels, energy policies addressing climate change, and source-specific control technologies. Furthermore, managers will need tools to link cause and effect, despite the complex, multiple changes occurring in emissions and climate.

Addressing these challenges would also address several challenges that were highlighted in three recent reports from the National Academies. In *Global Sources of Local Pollution: An Assessment of Long-Range Transport of Key Air Pollutants to and from the United States* (NRC, 2009a), improved satellite observations, in situ monitoring, and intensive field campaigns were all highlighted as ways to improve our understanding of air pollution transport. In *Air Quality Management in the United States*, (NRC, 2004) the highest priority recommendation for improving air quality management was to "[s]trengthen the scientific and technical capacity of the [air quality management] system to assess risk and track progress." Carefully designed and maintained monitoring can contribute to this progress by improving our understanding of ambient concentrations, emissions, transport, and deposition and by improving modeling through more complete data for model evaluation. Another of the panel's five recommendations was to "[e]nhance protection of ecosystems and other aspects of public welfare." Improved monitoring can contribute to this goal by tracking deposition, which impacts agriculture and ecosystems, and visibility degradation. Another National Academies report, *Observing Weather and Climate from the Ground Up: A Nationwide Network of Networks* (NRC, 2009b), cited four types of observations as the "highest priority observations needed to address current inadequacies," all of which are relevant for air quality monitoring:

3. Height of the planetary boundary layer
4. Soil moisture and temperature profiles
5. High-resolution vertical profiles of humidity
6. Measurements of air quality and related chemical composition above the surface layer

Given these assessment challenges, complex mitigation strategies, and changing climate, prospective observation systems design should explicitly recognize the utility of linking models and observations.

1.2 Uses of Air Quality Observations and Perspective of this Report

The observations surveyed in this report are used to monitor, elucidate, and assess air pollution to support diverse types of environmental decision-making and assessment. It is useful to segment out four broad disciplines or data clients to illustrate the purpose and limitations of this report to readers with a broad scope of perspectives: Health and Exposure, Ecosystems, Air Quality Management, and Atmospheric Processes and Climate. The demarcations among these four communities are often blurred, with considerable overlapping of assessment and data needs, and in practice the natural integration of interests across these disciplines should be taken into consideration. Nevertheless, it is important to consider the different perspectives of these communities.

Moreover, this report is written from the perspective of understanding the condition and processes of the atmosphere; many of the observations needed by these communities are not surveyed here. The focus is on the common needs from air quality observations.

Assessment of human exposure and health effects. Relating health effects to observed concentrations of pollutants is a critical use of air quality observations. Given the expense associated with designing, deploying, and operating a monitoring network, epidemiological studies of the health effects of air pollution typically use data from existing monitoring networks. For example, Pope et al. (2009) used measurements from EPA monitoring networks to show that decreases in $PM_{2.5}$ concentrations lead to increased life expectancy.

However, using current monitoring networks for epidemiological studies of air pollution is challenging. Monitoring networks depend on observations from small numbers of instruments to characterize the air quality in a metropolitan area, so those instruments are placed in representative areas that may not capture the range of concentrations to which people within the area are exposed. Likewise, monitoring networks of criteria pollutants are designed to provide pollutant levels over an averaging time defined by the national ambient air quality standards (NAAQS), which can prove limiting for some studies.

For measurements not directly related to compliance with air quality standards, such as speciation of particulate matter or ozone in the winter in many areas, which is well below air-quality standards and thus not closely monitored, the frequency of measurements can be considerably lower than ideal for epidemiological studies.

When data from an existing monitoring network are used to study health effects, the research is limited to the chemical species being measured by the network, as well as by pre-determined measurement periods and spatial coverage. In this way, the design of monitoring networks affects the health effects research that will depend on data from those networks.

It is important to note that health impacts are the primary inputs into the evolution of NAAQS, which in turn influence monitoring design. Other types of health impacts research complement the epidemiological studies which use ambient monitors, but the inter-relationship of the monitoring design and health effects studies illustrates the need for careful design of ambient monitoring programs.

Ecosystem and welfare assessments. Ecological health indicators are not addressed in this report, nor are physical and chemical properties of aquatic and terrestrial system. However, atmospheric observations are a major part of ecological effects assessment efforts, either directly or through air quality models. Watershed acidification, eutrophication, and direct damage to vegetation are examples of major ecosystem welfare issues linked directly to atmospheric characterization studies. The ecosystem assessment community is an important client of air quality observations, using these data as inputs to ecosystem exposure models and as trend indicators relating the effectiveness of emission strategies on atmospheric deposition. The characterization demands for ecosystem analyses may be as demanding as those associated with human health and exposure communities given the spatial heterogeneity of vegetation, soil types, and microclimates within and across watersheds and ecosystems that affect atmospheric deposition. Furthermore, most of our monitoring stations are distributed according to population-weighted criteria, creating major information gaps in sensitive ecosystems. Air pollution can affect ecosystems via more complex exposure pathways, relative to human health, complicating the relationship between ambient concentrations and ecological effects, and illustrating the need for interoperable data systems capable of using multiple types of observations and model outputs.

The 2004 NAS study mentioned above (NRC, 2004) emphasized the linkages between atmospheric and terrestrial and aquatic media. To that end, this report emphasizes the importance of atmospheric nitrogen measurements, a major input for downstream ecosystem models and an area with considerable spatial, temporal, and species observational sparseness.

Air Quality Management. Air quality management practice includes the establishment of human- and ecosystem-health-based standards and the subsequent development of rules, programs, and implementation steps designed to achieve the emission changes needed to meet air quality targets. The cyclic nature of air quality management reflects both the evolution of air quality standards (based on improving knowledge of the effects of air pollution) and evaluation of whether implemented programs produced intended results. In recent years, air quality management has sought more direct evidence of the connections along the source-to-effects continuum, and of the relationship between emissions changes and air quality improvements, to better assess the effectiveness of emission strategies.

The regulatory nature of air quality management decisions places special demands on the observations used to support this work. Ambient monitoring of criteria air pollutants such as ozone, particulate matter, etc., is designed to be used to determine if an area is compliant with a specified NAAQS. Only certified measurements from Federal Reference or Equivalent Methods (FRM/FEM) can be used for comparison to the NAAQS. However, FRM/FEMs have not been established for hazardous air pollutants. In practice, the lack of a FRM/FEM significantly hinders commercialization of technologies, effectively preventing wide deployment of a monitoring method.

Major aspects of air quality management include the cyclic review of air quality standards and the development and review of implementation plans which describe how a jurisdiction will come into compliance with standards. Air quality observations, particularly from ambient monitoring, are critical to this work. However, atmospheric models are an essential part of this process. The development and evaluation of models is discussed in the next section.

Understanding and forecasting atmospheric processes and air quality-climate links. This category considers data uses associated with improving characterization of physical and chemical processes underlying pollutant release, transformation, and removal. These disciplines have important client and provider roles, including development, evaluation, and improvement of numerical atmospheric chemistry models. Models are critical components in air quality management and assessment of air quality on health, ecosystems, and climate. They are fundamentally required for future predictions, such as air quality forecasts, climate predictions, or predictions of response to future emissions changes. However, they are also a key complement to observations in understanding the current or historical state of the atmosphere.

A core mission of the atmospheric science community is to advance the ability to characterize the five-dimensional (space, time, and species) chemical state of the atmosphere. The limited coverage in all five of these dimensions limits the utility of routine observations in atmospheric science applications. The practical advancement of this ability depends on iterative use of both atmospheric observations and models, as neither is sufficient to characterize the atmosphere with the detail needed to support applications.

As surveyed in Chapter 2, both intensive field campaigns and observations from space provide valuable measurements not captured in routine observation networks. For example, these observations constitute most of our measurements of pollutants above the surface layer, and almost all direct observations of inter-regional or intercontinental pollution transport. These measurements have had direct impacts on the air quality management process. For example, results from the Texas Air Quality Study were incorporated into the ozone State Implementation Plan for the Houston area within two years.[1] Satellite observations have played important roles in improving the quality of fire based emissions in EPA's emissions systems for driving air quality models. In the absence of an adequate surface-based network, satellite observations have been used to demonstrate the progress of major national programs to reduce emissions of oxides of nitrogen.

Integrating these various types of observations with one another and with models to produce the best five-dimensional characterization of air quality is a significant scientific and information technology challenge, even in a research setting. Integration for decision-support purposes, for near-real-time forecasting applications, and other operational purposes is even more challenging. While recent work and examples have shown the value of this approach as agencies react to the challenges discussed in section 1.1, significant hurdles prevent realization of greater value from these observations and engagement of a broader user community.

Perspective of this report. As mentioned above, this survey of air quality observation systems considers the major systems which are used to characterize the physical and chemical state of the atmosphere for the purpose of assessing air quality, and then in turn the impact of air pollution on human health, ecosystems, and climate. As such, the survey

[1] http://www.tceq.state.tx.us/implementation/air/airmod/texaqs

considers many of the observations needed to assess air quality management and many significant related observations needed to understand atmospheric processes and air quality-climate links. Developing methodologies to effectively integrate various types of observations, and models, to best characterize the five-dimensional state of the atmosphere, is an important challenge that this report considers in Section 3.2.

This report does not attempt to capture the major needs or existing gaps of our observation programs as they support human exposure and health effects studies or ecosystem impacts studies. Human exposure assessments generally place added demand on observations, for more highly resolved temporal and spatial data reflecting the complex distribution and exposures of populations and individuals. Nor does this report directly address integration of ambient air quality observations with other data needed for health or exposure assessments.

The challenges facing human exposure and health effects are similar to those faced by the air quality management and ecosystem exposure assessment communities - the desire for richer observation sets in species, spatial, and temporal resolution. Coordinated planning and deployment of observing systems between these communities and the agencies and offices that serve them will allow these communities to realize more value from existing and future observations.

1.3 Relationship to Other Strategies and Organizational Structures

Over the last several years a number of observational strategies and umbrella organizations have formed that convey and promote integration across disciplines and/or organizations, with goals similar to those discussed here. Some of these efforts are focused on air quality or atmospheric chemistry, while some are far broader. These strategies and organizations include:

GEOSS/GEO/USGEO – The Global Earth Observation System of Systems (GEOSS - http://www.earthobservations.org/geoss.shtml) is an overarching framework coordinated and promoted by the Group on Earth Observations (GEO), a international voluntary partnership of national governments and international organizations. GEOSS is envisioned as a multidisciplinary system-of-systems which will use standards and interoperability to make all types of Earth science data more findable, accessible, and useable for decision support. Since 2005, GEOSS has spurred a variety of U.S. programs in NASA, NOAA, and EPA intended to link a range of air quality observation systems and facilitate information access through information technology standards and prototype systems. The U.S. government response to GEOSS is coordinated by the U.S. Group on Earth Observations (USGEO), organized as a subcommittee under the Committee on Environment and Natural Resources (CENR).

IGAC / AC&C – The International Global Atmospheric Chemistry (IGAC, http://www.igac.noaa.gov) program was created in the late 1980s to address growing international concerns about atmospheric changes. IGAC is jointly sponsored by the Commission on Atmospheric Chemistry and Global Pollution (CACGP) of the

International Association of Meteorology and Atmospheric Sciences (IAMAS) and the International Geosphere-Biosphere Programme (IGBP). IGAC has initiated or coordinated much of the research of the last decade focusing on chemical composition, transformations, and transport in the troposphere. Together with the SPARC (Stratospheric Processes and Their Role in Climate) project of the World Climate Research Programme (WCRP), IGAC has started the Atmospheric Chemistry and Climate (AC&C, http://www.igac.noaa.gov/ACandC.php) initiative, which examines the interplay between chemistry, chemically active species, and climate change.

IGACO – Integrated Global Atmospheric Chemistry Observations (http://www.igaco-o3.fi) is a strategy for bringing together ground-based, aircraft, and satellite observations of 13 chemical species in the atmosphere. IGACO will be implemented as a strategic element of the Global Atmospheric Watch (GAW) program of the World Meteorological Organization (WMO). IGACO will be organized around four focus areas, one of which is air quality / long-range transport. IGACO provides specific recommendations on measurement parameters and facilitates integration across satellite and ground based stations. Although IGACO is focused on large, global-scale characterizations, the strategy provides useful guidance that should be considered in any air-based observation program design. Several of the core IGACO measurement parameters (O_3, CO, NO_2, CO, CO_2) are important regional- and urban-scale air quality indicators.

MACC – Monitoring Atmospheric Composition and Climate (http://www.gmes.info/pages-principales/projects/atmosphere-projects/macc/) MACC is a recently-initiated collaborative effort, funded by the European Commission, to monitor global distribution and long-range transport of long-lived greenhouse gases, aerosol, and reactive pollutants which degrade air quality. MACC's product lines include data records on atmospheric composition for recent years, and current data for monitoring present conditions and forecasting the distribution of key constituents for a few days ahead. (MACC is a continuation of the GEMS and PROMOTE programs under GMES, see above website for details.)

NARSTO – NARSTO (http://www.narsto.org/) is a North American public-private partnership of government agencies, industry, and academic institutions that sponsors a variety of workshops and assessments addressing current air quality research interests. NARSTO traditionally has focused on the atmospheric sciences with assessments addressing ozone and particulate matter air pollution, emissions inventories and, more recently, multiple-pollutant air quality management. These assessments generally complement preceding NAS studies addressing air pollution management. The NARSTO Data archive stores a data from a variety of intensive field campaigns. NARSTO originally was called the North American Research Strategy for Tropospheic Ozone (NARSTO) and since has abandoned that acronym in keeping up with current priority air quality issues.

NAAMS – The National Ambient Air Monitoring Strategy (http://www.epa.gov/ttnamti1/monitor.html) was developed jointly by the EPA and numerous State and local agencies. Developed in the early part of the 2000s, NAAMS (Scheffe et al., 2009) was intended to make more efficient the design of U.S. regulatory-based networks supporting development of air quality standards and emission control strategies. The multiple pollutant National Core network (NCore, see section 2.1) emerged from the NAAMS process.

The scope of this report is broader than that of the NAAMS for routine networks, though it is focused on U.S. federal agency programs (while recognizing the importance of international transport and climate on U.S. air quality). Section 2 presents a broad overview of air quality monitoring and observation programs that include routine surface-based networks, intensive studies, satellite observations, vertical profile measurements, and other special purpose networks. Section 3 addresses issues associated with maintaining and advancing these programs to assess current and emerging air quality issues. Section 4 recommends establishing a standing multi-agency task force for addressing a variety of air monitoring issues and related data gaps that require coordination and/or action.

This report is presented by the Air Quality Research Subcommittee (AQRS) of the Committee on Environment and Natural Resources. As described in section 4, this report recommends establishment of a standing Working Group on air quality observations. This group would report to AQRS.

2 Overview of Observation Programs

A variety of measurement programs support air quality assessments. These include:

- routine regulatory and deposition networks
- intensive aircraft and ground-based field studies
- radiosonde programs
- satellite measurements
- ground-based remote-sensing networks
- focused, fixed-site, special purpose networks

Brief overviews of these systems are provided as a basic inventory to help frame subsequent discussions on strengths, gaps, and recommendations. More detailed information is available in the appendices.

Major networks currently operating are emphasized; reference to other networks that have been discontinued, or that were only intended for a specific operating period, is also provided. The focus is on routinely operating North American networks, with limited mention of European and international efforts relevant to North American assessments.

2.1 Routine Surface-Based Ambient Air and Deposition Networks

Routine ambient air and deposition monitoring networks in North America provide over 3000 fixed platforms (Figure 1) measuring numerous gaseous species and aerosol properties; see Appendices A and B. As described below, many of these longstanding U.S. networks have been required or catalyzed by the 1970 Clean Air Act (CAA), subsequent CAA amendments, National Ambient Air Quality Standard (NAAQS) reviews, and National Academy of Sciences (NAS) recommendations fostering periodic adjustments to our routine networks. Federal regulations describe how sites in these networks are to be located, and describe the Federal Reference Methods (FRM) or Federal Equivalent Methods (FEM) for the measurements made at many of the required sites.

Examples include the Clean Air Status and Trends Network (CASTNET) and National Atmospheric Deposition Program (NADP) addressing acidification; the Photochemical Assessment Measurement Stations (PAMS) in response to persistent ozone pollution, and the $PM_{2.5}$ monitoring networks following promulgation of the 1997 NAAQS.

Most routine air quality monitoring stations in the US are owned and operated by nearly 300 state and local governmental and Tribal agencies. These state and local air monitoring sites (SLAMS) are the principal source of ambient measurements of the six criteria air pollutants (ozone, nitrogen dioxide, carbon monoxide, sulfur dioxide, lead, PM_{10} and $PM_{2.5}$), each of which has one or more NAAQS specifying a specific concentration level and averaging period (http://www.epa.gov/ttn/naaqs/). Most of these networks also include stations operated by federal agencies, typically in rural / remote sites. These networks are indirectly supported by extensive meteorological networks (Appendix C).

The national air monitoring regulations for U.S. programs are codified in the Code of Federal Regulations (CFR) parts 50, 53 and 58. Funding for these programs is through CAA Section 103 and 105 federal grants to agencies and tribes. States and local agencies are required to match federal Section 105 contributions.

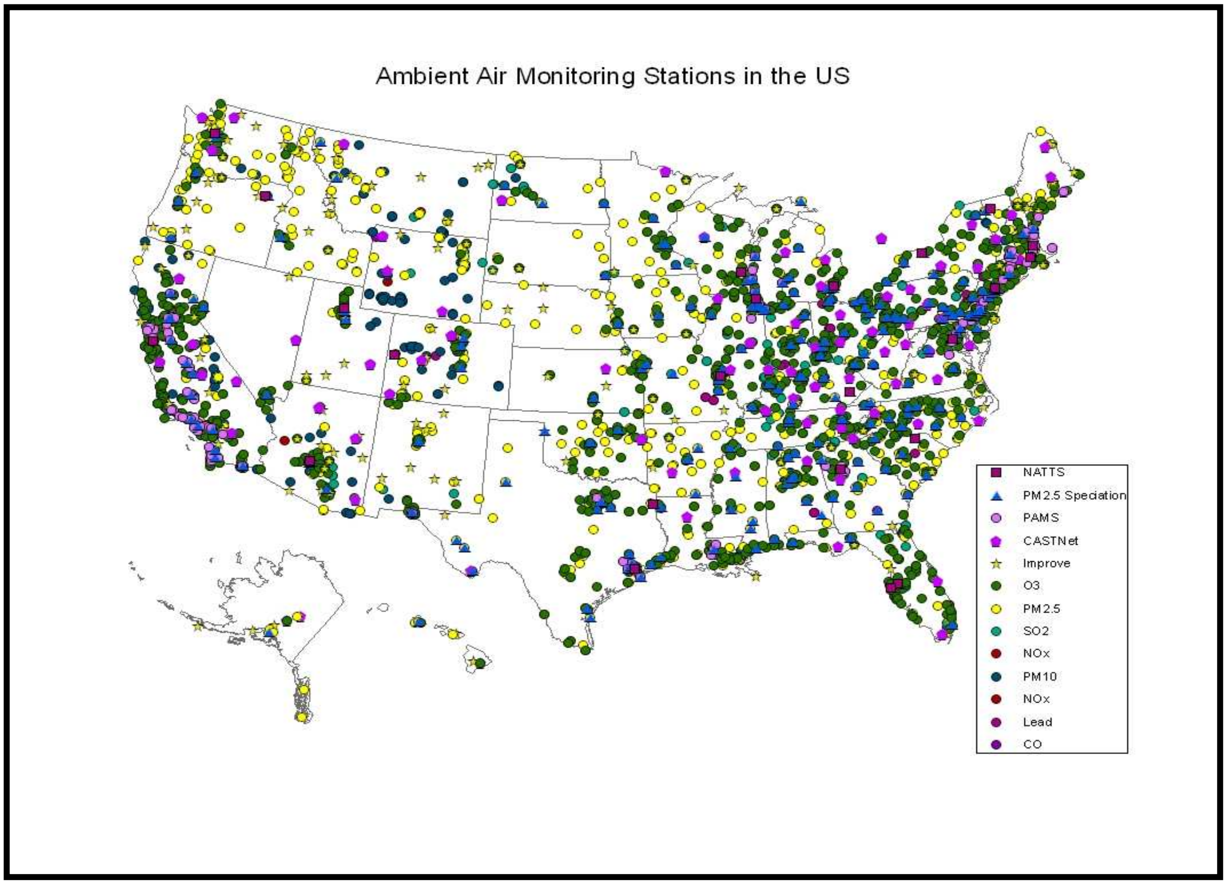

Figure 1. Aggregate map of the majority of routine U.S. monitoring stations illustrating relatively broad coverage across the continental U.S. Note spatial gaps in sparsely populated areas.

Criteria Gas and Ozone Precursor Monitoring

Criteria gas networks -- Approximately 1500 surface stations measure some combination of criteria gases, with nearly 1100 of these stations measuring ozone, using FRMs or FEMs. Several hundred monitors report concentrations for CO, SO_2 and NO/NOx. The majority of these stations are SLAMS, although Federal Agency networks such as CASTNET, National Park Service (NPS) monitors, and a variety of special purpose monitors provide additional coverage (see appendix). CASTNET and NPS provide the majority of rural criteria gas platforms.

Photochemical Assessment Monitoring Stations (PAMS) -- Approximately 75 sites in 22 cities were deployed by state and local agencies in the early 1990s to measure ozone precursors, largely in response to a 1991 National Research Council study. PAMS and the air toxics network (see below) provide the majority of routinely available non-methane organic carbon (NMOC) measurements. A number of C2-C10 alkanes and alkenes, aromatics, formaldehyde, and acetaldehyde are measured using a combination of continuous methods and sampling techniques over 3- and 24-hour collection periods, often limited to the ozone season (April – October). The 1990 CAA Amendments required areas classified as serious and above with respect to contemporary (1990-1992) ozone NAAQS to implement PAMS, with minor modifications since then. Most VOC sampling sites include instrumentation for O_3 and NO/NOx.

Particulate Monitoring

$PM_{2.5}$, PM_{10} and $PM_{10-2.5}$ Mass Networks -- The 1997 promulgation of a fine particulate NAAQS (EPA, 1997) led to deployment of over 1500 $PM_{2.5}$ sites (about 1000 currently) used to determine whether an area complies with the standard. These sites use an FRM or FEM, sampling over 24 hours daily or every third or sixth day. Nearly 300 additional measurements not meeting FRM or FEM specifications are provided by the chemical speciation sites (see below). Approximately 600 stations provide indirect measurements of continuous (hourly resolution) $PM_{2.5}$ mass using a variety of techniques. To date, continuous $PM_{2.5}$ mass measurements have not been granted FEM status, although the revised monitoring regulations issued in 2006 (EPA, 2006) provided new approaches for demonstrating equivalency. This was intended to promote broader deployment of these methods.

Approximately 1000 PM_{10} samplers (24-hr sampling period, typically collected every 6^{th} day) remain in operation. Although a $PM_{10-2.5}$ standard has not been promulgated, EPA developed a $PM_{10-2.5}$ FRM based on mass difference of concurrent PM_{10} and $PM_{2.5}$ measurements. Such $PM_{10-2.5}$ measurements are planned for the 75-site NCore network (see below).

Interagency Monitoring of Protected Visual Environments (IMPROVE) Program -- The IMPROVE network, with over 100 sites, has provided nearly a two-decade record of major components of $PM_{2.5}$ (sulfate, nitrate, organic and elemental carbon fractions, and trace metals) in pristine areas of the United States (see Figure 2. IMPROVE is led by the NPS; various federal and state agencies support operations. The primary focus of the network is to track visibility and trends in visibility.

$PM_{2.5}$ Chemical Speciation Monitoring -- In addition to the IMPROVE network, over 300 EPA speciation sites were added from 2000 - 2002 in urban areas of the United States to assist $PM_{2.5}$ assessment efforts. No FRM exists for particulate speciation, which is not directly required to determine attainment, and there are slight differences between monitors and methods used in the STN. However, the network's coverage (Figure 2) across urban and rural areas has proved essential for a wide range of research and analysis. The speciation networks typically collect a 24-hour sample every three, and sometimes six, days. Daily 24-hour speciation collection is limited to occasional efforts in the SEARCH (see below) network. Similarly, only a handful of sites provide near continuous speciation data, usually limited to some combination of sulfate, carbon (organic and elemental splits) and nitrate. This enables insight into diurnal patterns for diagnosing various cause-effect phenomena related to emissions characterization, source attribution analysis and model evaluation. In addition, the National Air Toxics Trends

Stations (NATTS, see below) include aetholometer measurements used as a surrogate for elemental carbon.

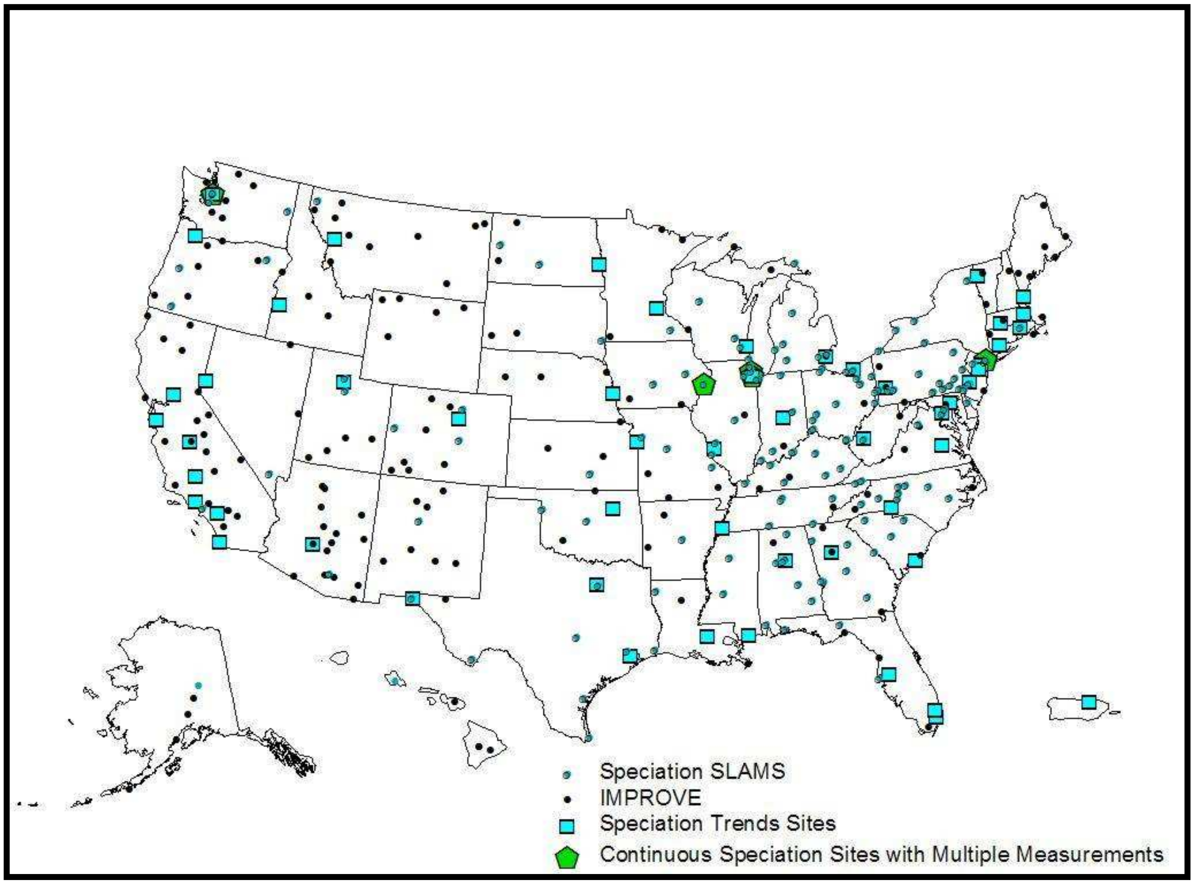

Figure 2. Locations of chemical speciation sites delineated by program type.

SouthEastern Aerosol Research and Characterization (SEARCH) Study -- This study experiment is an industry funded network of 8 sites that originally emerged from the Southern Oxidants Study (SOS) in the 1990s and has operated for nearly a decade. SEARCH provides an array of standard criteria pollutant measurements but also includes daily PM speciation at selected times and locations, gaseous ammonia, reactive nitrogen (NOy), and true nitrogen dioxide (i.e., a measurement of NO_2 concentration unaffected by other nitrogen oxides, which contaminate FRM NO_2 measurements, see section 3.1.1). These measurements are not available in the major government-funded routine networks.

PM Supersites Program -- This program (Solomon et al., 2008) provided highly resolved aerosol measurements at eight U.S. cities for several time periods from 1999 through 2004, with some sites collecting data after 2004. A number of instrument configurations were deployed, ranging from additional locations for standard speciation monitors, to systems capturing near-continuous size-dependent speciation profiles.

The National Core (NCore) Network

NCore (Scheffe et al., 2009) is a 75-site multiple pollutant component of the routine networks that was fostered by the Ambient Air Monitoring Strategy for State, Local, and Tribal Air Agencies (EPA, 2004) and was promulgated in the 2006 CFR as part of the new monitoring rule (EPA, 2006). NCore is designed to capture urban- and regional-scale representative concentrations of a variety of trace gases (CO, SO_2, NOy, NO) and aerosols (PM_{10} and $PM_{2.5}$ mass and chemical speciation) to support a range of health effects, model evaluation and research studies. The NCore sites are designated multiple pollutant sites that require co-location with existing $PM_{2.5}$ chemical speciation sites. Full deployment is scheduled for 2011.

Air Toxics Monitoring Program

National Air Toxics Trends (NATTS) Network -- State and local agencies have measured a variety of metallic and gaseous hazardous air pollutants (HAPs) at over 200 locations since the 1980s. Broad access and use of those data were hampered by a lack of centralized databases and multiple sampling and laboratory protocols, creating data quality and consistency concerns. To address these inconsistencies, the NATTS network was conceived in 2001 and consists of 27 sites. The sampling protocol typically has been every sixth day for 24 hours.

Among the priority ranked 33 air toxics of US concern, observations of benzene and other common aromatics are fairly widespread and relatively reliable. However, other potentially important species are less well represented in air monitoring. During the initial start-up of the NATTS, six priority HAPs (formaldehyde, benzene, 1, 3-butadiene, hexavalent chromium, acrolein and arsenic) were targeted for inclusion based on results of the 1996 National Air Toxics Assessment (http://www.epa.gov/ttn/atw/nata/). Based on efficiencies in methodologies and the 1999 NATA, NATTS observations expanded to include the following:

> Gas-phase compounds: acetaldehyde, acrolein, benzene, carbon tetrachloride, chloroform, dichloropropane, dichloromethane, formaldehyde, naphthalene, perchloroethylene, trichloroethylene, vinyl chloride, 1,3-butadiene, and 1,2-tetrachloroethylene.
>
> Metals in PM_{10}: nickel, arsenic, cadmium, manganese, beryllium, and lead.
>
> Total suspended particle (TSP) mass: hexavalent chromium
>
> Combined gas-phase and TSP: naphthalene and benzo(a)pyrene.
>
> Light absorbing carbon through aetholometry at a subset of sites.

The IADN program (see below) analyzes for selected metals (As, Pb, Cd, Se) and other toxics, while the NADP includes Hg monitoring in some sites. These programs are discussed below.

Deposition Networks

Precipitation based networks: NADP and IADN -- Precipitation chemistry is an important link between atmospheric and terrestrial and aquatic systems. The National Atmospheric Deposition Program (NADP) oversees a network of over 250 sites that analyze for ions which have significant acidification and eutrophication effects. The NADP includes a seven-site Atmospheric Integrated Research Monitoring Network (AIRMoN), which provides greater temporal resolution for acidifying/eutrophying ions, and the Mercury Deposition Network (MDN, over 90 sites).

The Atmospheric Mercury Network (AMNet) provides data on the atmospheric concentrations of mercury in gaseous and particulate forms, and other data needed to estimate dry deposition at twenty sites across North America. Monitoring mercury in the atmosphere is important for model evaluation and tracking the atmospheric response to emissions reductions. AMNet, which began as a pilot partnership networking and standardizing previously deployed instruments, was formally adopted by NADP in 2009.

The joint Canadian-U.S. Integrated Atmospheric Deposition Network (IADN) includes a mix of stations across the Great Lakes that sample both precipitation and ambient air for a range of toxic compounds. IADN emphasizes many of the more persistent organic compounds including PCBs, pesticides, dioxins and toxics metals (lead, cadmium, arsenic and selenium).

Clean Air Status and Trends Network (CASTNET) -- CASTNET was established in the early 1990s to track changes in dry deposition of major inorganic ions and gaseous precursors associated with the CAA Title 4 reductions in sulfur and nitrogen, designed to address surface water acidification in eastern North America. The network of over 80 sites has expanded from an Eastern U.S. focus to cover large areas in the West. CASTNET provides weekly averaged ambient measurements of major ions (sulfate, nitrate, calcium, sodium, potassium, ammonium, and magnesium) integrated over all aerosol sizes. A subset of sites includes ozone and IMPROVE $PM_{2.5}$ speciation instruments. CASTNET site locations were designed to reflect regional scale air mass samples, relatively free from local urban source signals. The ambient concentrations are used in algorithms that estimate deposition velocity to calculate dry deposition.

Other air monitoring networks

For completeness, European air monitoring networks and national/international networks for monitoring persistent organic pollutants (POPs) are listed respectively in Appendices D and E.

Accessing surface network data

Access to routine measurements is available through:

- EPA's Air Quality System (http://www.epa.gov/ttn/airs/airsaqs/) and related DataMart (http://www.epa.gov/ttn/airs/aqsdatamart/) which house criteria gas, PAMS, PM mass, PM speciation and air toxics data.

- EPA's AIRNow (http://airnow.gov/) and AIRNowTech (http://www.airnowtech.org/) provides near real time access to ozone and continuous $PM_{2.5}$ mass data.
- VIEWS (Visualization Information Exchange Web System - http://vista.cira.colostate.edu/views/ - developed by the Regional Planning Organizations (RPOs) in support of visibility assessments) houses IMPROVE and EPA $PM_{2.5}$ speciation data.
- CASTNET (http://www.epa.gov/castnet/), NADP (http://nadp.sws.uiuc.edu/), and IADN (http://www.msc-smc.ec.gc.ca/iadn/index_e.html) provide direct access to deposition data. NADP data includes subnetworks (NTN, MDN) and AIRMoN (http://nadp.sws.uiuc.edu/airmon/).
- The Health Effects Institute (HEI) air quality database provides access to and analysis tools for processed $PM_{2.5}$ chemical speciation data (http://hei.aer.com/aboutDatabase.php).
- Supersites Integrated Relational Database (SIRD) is described at http://www.epa.gov/ttn/amtic/ssdatamg.html .
- Southeastern Aerosol Research and Characterization (SEARCH) Study is described and the availability of data is identified at http://www.atmospheric-research.com/studies/SEARCH/index.html.

2.2 Intensive Field Campaigns

Intensive field campaigns (see Appendix F) of relatively short duration supplement routine long term monitoring networks by measuring spatial, temporal, and compositional distribution of pollutants and precursors. These studies are designed to investigate the emission and physical and chemical processing of precursors and pollutants to understand the source, fate, transport, and removal of these species. Typically, these campaigns utilize some combination of aircraft- and/or ship-based studies, satellite and ground-based remote sensing, research-grade instrumentation, and advanced analytical methods. These efforts complement routine ground based measurements, which usually do not address reactive gaseous species, aerosol size distributions, organic chemistry characterization, and vertically stratified data.

There has been a long history of intensive field campaigns starting with the Regional Air Pollution Study (RAPS) in the 1970s which formed the basis for evaluating the early photochemical models used in acid deposition and ozone assessments. Landmark campaigns in the United States through the 1980s and 1990s such as the Southern California Air Quality Study, the San Joaquin Valley Air Quality Study (SJAQS)/Atmospheric Utility Signatures, Predictions, and Experiments (AUSPEX), and the Southern Oxidant Study (SOS) were reviewed as part of the 2000 NARSTO ozone assessment (Solomon et al, 2000). Over the last decade there have been a series of field campaigns focusing on characterization of surface level aerosols through the PM Supersites program (Solomon et al., 2008).

While the early campaigns focused on urban environments, the Eulerian Model Evaluation Field Study (EMEFS) and SOS during the early 1990s shifted focus toward regional spatial scales, consistent with the dominant air pollution concerns of the time, acid rain and ozone. In addition to addressing urban areas of concern such as Houston and Los Angeles, more recent campaigns have extended spatial scales beyond regional studies to address long-range transport and continental scale atmospheric processes. Some of these campaigns include: (1) local and regional studies for the northeast and southeast U.S., portions of Texas, and central and southern California; and (2) intercontinental studies of transport across North America and the Atlantic, Pacific, and Indian Oceans. A variety of federal (particularly NOAA and NASA) and state entities have served as lead agencies for these studies. Appendix F provides a listing of key studies conducted since the late 1990s with important earlier campaigns identified in footnotes. Several recent, highly relevant campaigns are briefly described here.

The Intercontinental Transport and Chemical Transformations project of 2002 (ITCT-2k2) investigated springtime transport along the Pacific coast of North America. This campaign combined ground- and aircraft-based measurements along with model simulations and satellite data products to examine the tropospheric chemistry and transport of ozone, fine particles and chemically active greenhouse compounds. This study shed light on the intercontinental transport of ozone and aerosols, and the impacts this transport has on air quality and climate.

In 2004, the International Consortium for Atmospheric Research on Transport and Transformation (ICARTT) served as an organizing umbrella for North American and European field campaigns addressing regional scale processes in both continents as well as trans-Atlantic transport phenomena (Fehsenfeld et al., 2006). The North American studies included the Intercontinental Chemical Transport Experiment - North America (INTEX-NA 2004 and 2006) and the New England Air Quality Study - Intercontinental Transport and Chemical Transformation (NEAQS – ITCT 2004) programs. These ICARTT campaigns provided insights into trans-Atlantic processing of ozone precursors, lightning-generated NO_x emissions, secondary organic aerosol processes, and biomass burning based on a variety of satellite, aircraft, ship-based, and ground-based measurements.

The ICARTT campaigns were preceded by the North American Regional Experiment (NARE) in the 1990s that studied synoptic scale transport in the North Atlantic (Fehsenfeld et al., 1996; Penkett et al., 1998). The Transport and Chemical Evolution over the Pacific (TRACE-P) campaign of 2001 catalyzed much of our current understanding of Asian outflow to North America. The INTEX-NA mission was followed by the 2006 INTEX-B aircraft mission, which studied pollutant transport flow across the north Pacific and into the western United States. INTEX-B was also linked with the 2006 MILAGRO mission, which studied pollutant outflow from Mexico City. Most of the large intercontinental scale field campaigns are considered key parts of the IGAC program (Section 1.3). Findings specific to Northern Hemisphere transport have been synthesized by the Hemispheric Transport of Air Pollution (HTAP) task force (Keating and Zuber, 2007).

The Texas Air Quality studies (TexAQS and TexAQS II) during 2000 and 2006 were intensive research campaigns designed to address some of the unique VOC chemistry and transport features of southeastern Texas. The 2006 program extended the earlier study to address climate-air quality linkages and probe nighttime NOx and NOy chemistry.
The Bay Region Atmospheric Chemistry Experiment (BRACE) was conceived in response to persistent increasing trends of nitrogen oxide emissions in Florida, in order to assess its potential effects on air quality and the ecological health of Tampa Bay and its surroundings. The BRACE program began in 2000 and has included both long-term and short-term intensive measurement campaigns, focusing on assessment of atmospheric nitrogen deposition to Tampa Bay. This program served to help develop modeling approaches for numerous eastern US estuaries and has been augmented by additional field campaigns elsewhere, most notably in eastern North Carolina. Key participants included the Florida Department of Environmental Protection, Tampa Bay Electric Company, EPA, NOAA, Argonne National Laboratory, numerous universities and several additional Florida agencies.

The PM Supersites program (see section 2.1) complemented deployment of the routine $PM_{2.5}$ routine monitoring program by deploying research instrumentation in intensive field campaigns for highly time-resolved data on multiple aerosol physical and chemical properties in major U.S. cities (Atlanta, Baltimore, Fresno, Houston, Los Angeles, Pittsburgh, St. Louis, and New York). These data sets, spanning portions of 1999 – 2004 with some sites operating in later years, were intended to address three primary objectives: development of monitoring methods and transfer to operational agencies, support for health effects research, and State Implementation Plan (SIP) development. Several findings are synthesized in dedicated special journal issues (Pandis et al., 2005; Geller and Solomon, 2006; Solomon et al., 2008).

The Los Angeles Supersite and the Southern California Particle Matter Center spawned interest in near-roadway characterizations by providing measurements of particles, particularly ultrafine particle number, near highways. This work showed very high particle concentrations near the highway (Zhu et al., 2002), with concentrations decreasing and size distributions changing with increased distance from the roadway. Near-roadway studies have since been undertaken, primarily by EPA, in several other cities, including Detroit, Raleigh, and Las Vegas. Given the high pollutant concentrations and the high human exposures to both gaseous and particulate pollutants near many highways, near-roadway measurements and studies provide an important bridge between atmospheric science and health science.

The Polar Study using Aircraft, Remote Sensing, Surface Measurements and Models, of Climate Chemistry, Aerosols, and Transport (POLARCAT) was a coordinated international series of field studies that was part of the International Polar Year (IPY). As part of this, NASA led the 2008 Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) project. This field study addressed a variety of issues impacting the Arctic atmosphere, including Eurasian and North American fires, halogen chemistry, light absorbing carbon and persistent pollutants. NOAA led two field studies as part of IPY: Aerosol, Radiation, and Cloud Processes affecting Arctic Climate

(ARCPAC) and International Chemistry Experiment in the Arctic LOwer Troposphere (ICEALOT). ARCPAC involved the deployment of the NOAA WP-3D aircraft in Alaska and ICEALOT involved the deployment of the Woods Hole Research Vessel *Knorr* in the North Atlantic. Additionally, DOE led the Indirect and Semi-Direct Aerosol Campaign (ISDAC) as part of IPY as well.

The scheduled 2010 CalNex campaign will build on existing California programs and is intended to address air quality and climate linkages.

Field campaign websites

ARCTAS: http://www.espo.nasa.gov/arctas/
CalNex: http://www.esrl.noaa.gov/csd/calnex/
ICARRT: http://www.esrl.noaa.gov/csd/ICARTT/index.shtml
INTEX-B: http://www.espo.nasa.gov/intex-b/index.html
INTEX-NA: http://cloud1.arc.nasa.gov/intex-na/
MILAGRO: http://www.eol.ucar.edu/projects/milagro/
NEAQS - ITCT 2004: http://www.esrl.noaa.gov/csd/2004/
POLARCAT, http://www.polarcat.no/
TRACE-P: http://www-air.larc.nasa.gov/missions/tracep/tracep.htm
TexAQS & TexAQS II: http://www.esrl.noaa.gov/csd/2006/

2.3 Satellite–Based Air Quality Observations

An extensive array of satellite-based systems (see Appendix G) measuring total atmospheric columns and limited vertical profiles of several key species has been established by the United States and countries of the European Union. In the U. S., these programs are led by the National Aeronautics and Space Administration *(*NASA) and the National Oceanic and Atmospheric Administration (NOAA); in Europe they are led by the European Space Agency (ESA) and Eumetsat. NASA and ESA typically demonstrate new capabilities for Earth observations while NOAA and Eumetsat conduct long-term operational observations. A suite of satellites including Terra, Aqua, Aura, CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation), and Glory, as well as NOAA-17, NOAA-18, NOAA-19, and NPP (NPOESS [National Polar-orbiting Operational Environmental Satellite System] Preparatory Project), have been launched since 1999 or have near-term launch dates. Collectively, they measure columns and/or profiles of aerosol optical depth (AOD), O_3, H_2O, CO, CH_4, SO_2, NO_2, CFCs, other pollutants, and atmospheric parameters such as temperature. Most of these satellites have a near-polar low Earth orbit (LEO), passing twice per day over a given location. (For many species, measurements are only possible during daylight, so only one measurement is made per day per instrument.) The Earth Observing System (EOS) Afternoon Constellation, or "A-Train," is a group of several of these satellites (Aqua, Aura, CALIPSO, CloudSat, and PARASOL (Polarization & Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar), with Glory planned for addition in 2010) that fly in formation, crossing the equator a few minutes apart near 1:30 PM local time. The near-simultaneous observations from these satellites produce a rich picture of earth weather, climate, and atmospheric conditions. The OCO (Orbiting

Carbon Observatory) mission, which failed on launch in early 2009, was to join the A-Train to measure CO_2 with the precision required to map global distribution of CO_2 sources and sinks on regional scales. A U.S. replacement mission for OCO is not currently scheduled, but Japan's Greenhouse gases Observing Satellite (GOSAT), launched in January, 2009, will globally monitor CO_2 and CH_4.

NOAA's National Environmental Satellite and Data Information Service (NESDIS) oversees operations of U.S. geostationary and polar operational satellite programs (GOES and POES), providing imagery for weather forecasting and observations of light scattering relevant to aerosol characterizations.

For the future, NASA and partner agencies have proposed to deploy additional satellite platforms capable of measuring trace gases and aerosols to enhance the characterization of tropospheric air quality from space (NRC, 2007; Fishman et al., 2008). Specifically, the National Research Council (NRC) has recommended that NASA implement a number of missions over the next decade, in addition to implementing the NPOESS and GOES programs. These "Decadal Survey Missions" include:

(1) Geostationary Coastal and Air Pollution Events (GEO-CAPE) will partially focus on supporting air quality assessments and forecasts by measuring atmospheric columns with a frequency less than one hour from a geostationary spacecraft.

(2) The Aerosols, Clouds and Ecosystems (ACE) mission will consist of a lidar for characterizing aerosol height and properties and a polarimeter for determining aerosol types.

(3) Global Atmospheric Composition Mission (GACM) will focus on ozone and related gases for intercontinental air quality and stratospheric ozone layer monitoring, from a LEO spacecraft.

Satellite data complement surface networks and aircraft campaigns and are essential tools for evaluating models and improving emissions inventories. Satellite observations do not directly correspond to in-situ measurements of pollutant concentrations. Thus, the use of satellite data for air quality forecasting, management, health effects studies, and climate change assessments is complex. While satellites offer global or near-global coverage of several important species, there are basic limitations in using a space platform to effectively probe the lower levels of the atmosphere where exposure to pollution occurs. Understanding these limitations is important for gauging how these systems complement ground-based networks and support air quality management assessments.

Attributes of Air Quality Satellite Data Products

Fundamental Limitations -- Most satellite air quality observations are based on spectroscopic techniques using reflected, scattered, or emitted solar radiation as a broad source of radiation. While the science of measuring trace gases and aerosols from space is relatively mature, interferences related to variable surface reflectivity, cloud attenuation, and overlapping spectra of other species require significant processing and treatment. Even with this sophisticated data retrieval, most products will typically have significant spatial gaps for a given time period due to cloud interferences and other issues such as sun glint, etc. For example, aerosol events occurring at the same time as clouds are often screened out from the AOD products for NASA's Moderate Resolution Imaging Spectroradiometers (MODIS) aboard the Aqua and Terra satellites.

Moreover, most satellite sensors sum over the entire column of air from ground to satellite, while the highest interest is typically in concentrations near the surface, where people live. Some information on the vertical distribution of certain species can be obtained by the use of multiple observing angles for instruments in LEO, by limb sounding, active sensing, or other methods. For example, the CALIPSO satellite provides some ability to resolve aerosol vertical distribution. For certain important trace gases (e.g., NO_2, SO_2, HCHO) and aerosols, the majority of mass resides in the boundary layer of the lower troposphere, enabling associations linking column data to surface concentrations or emissions fields. For example, reasonable correlations (Engel-Cox et al., 2004), especially in the eastern U.S., have been developed between concentrations from ground level $PM_{2.5}$ stations and MODIS AOD, while correlations between MODIS AOD and surface aerosols are quite poor in the western U.S. due to excessive surface light scattering from relatively barren land surfaces.

In contrast to aerosols, most ozone resides in the stratosphere. Various techniques have been developed to extract the stratospheric signal to yield a tropospheric ozone residual (TOR), based on known homogeneities in the stratosphere and the use of chemical transport models and multiple measurements. Early approaches (Fishman, 1978) before and during the Total Ozone Mapping Spectrometer (TOMS) missions combined limb (angled view to characterize stratosphere) and nadir (downward view, characterizing total column) techniques to derive tropospheric ozone residuals. The 2004 launch of NASA's Aura mission, with multiple ozone sensors, is starting to produce more refined tropospheric ozone maps. For example, direct derivation of tropospheric column ozone is possible from the Ozone Monitoring Instrument (OMI) on Aura (Liu et al., 2009). However, differentiating ozone in the boundary layer from that in the free troposphere continues to pose significant challenges. This difficulty stems from strong molecular scattering of UV radiation in the boundary layer and surface emission in the thermal IR.

Temporal coverage -- The near polar orbiting tracks of most LEO satellites performing trace gas measurements deliver at most twice daily snapshots of a particular species (approximately 12 hours apart). In addition, measurements of many species can only be taken during the single daytime overpass. Consequently, these instruments can only observe temporal patterns of pollutants or time-integrations of pollutant concentrations or exposure at daily or longer scales. Furthermore, instruments in LEO have only a short exposure to each Earth scene, limiting the signal-to-noise ratio. For many LEO products, observations for a given day are quite noisy, and weekly or monthly averages are more typically used. Geostationary (GEO) satellite platforms, such as the NOAA GOES systems (http://www.oso.noaa.gov/goes/index.htm), do provide near-continuous monitoring of physical parameters for weather tracking and forecasting purposes. The ability of a GEO instrument to observe an area for longer time periods potentially enables a sufficient signal-to-noise ratio to make short time period observations, on the order of one hour, meaningful.

Spatial coverage -- Polar orbiting satellites typically provide horizontal spatial resolution between 10 and 100km for atmospheric composition. Spatial resolution less than 10 km is possible with GEO and LEO platforms. Observations of pollutants above the surface, delivered by satellite systems, complements ground-based in-situ measurement networks – especially considering that a considerable fraction of pollutant mass resides well above Earth's surface. However, as noted above, the sensitivity of satellites to elevated pollutants can obscure measurements of the boundary layer, and in general, satellite data products contain little or no information about the vertical distribution of pollutants. Furthermore, one technique used to obtain vertical distribution information, comparison of nadir and limb observations, is usable from GEO only if complementary limb observations are available from one or more polar orbiting satellites.

As an example, limitations of satellite data are further enumerated and elaborated for the GOME sensors (O_3, NO_2, HCHO) by the Coordinating Research Council, Inc. (Vijayaraghavan, et al., 2007).

Current Use of Satellite Data in Air Quality Management

In broad terms, satellite measurements serve as complements to other surface based and aircraft measurement programs and air quality models. Satellite applications for air quality forecasting and assessments are covered extensively in the published literature (Martin, 2008; Fishman et al., 2008;Vijayaraghavan et al., 2007). The following summary does not capture the full breadth of applications of satellite observations, but describes how these data are most effectively incorporated in air quality assessments. Three general methods are applied in the use of satellite observations in air quality assessments:

(1) ***Detecting evidence of long-range transport.*** Satellite data support assessments of air quality on hemispheric and global scales and assessments of long-range transport. These are projected to be of increasing importance to North American air quality management in the future (see section 1.2). Trans-oceanic air pollution transport can be observed with satellites, and direct observational evidence of this phenomenon has been clearly visible in satellite imagery (Figure 3).

(2) ***Characterizing emissions and air quality model support***. Satellite observations play an important role in emissions characterization, particularly for source regions and sectors that have inadequate bottom-up inventories. Applications include improving inventories from poorly-characterized, developing regions in Asia and from "natural" sources such as lightning and soil NOx. Biogenic VOC emission estimates have been developed (Millet et al., 2008) using satellite measurements of formaldehyde, a degradation product of directly-emitted isoprene. The location and source strength of wildfire plumes detected from space are important inputs for annual emissions inventories (Martin et al, 2006) used in EPA air quality models such as CMAQ. Sustained long-term satellite observations support accountability analyses of efficacy of implemented programs. Due to a lack of surface-based true NO_2 measurements, satellite observations have been the most useful indicators of progress in the NOx SIP Call. Inverse modeling (the process of using a CTM to estimate the emissions that would reproduce the satellite observations) is frequently used in deriving "top-down" emissions which can improve and update emissions from "bottom-up" inventories.

Air quality management depends on models for complex environmental characterizations that can not be achieved through observations alone (see section 1.2). Satellite-based enhancements to surface monitoring networks will support the evaluation of these models by intercomparison and improving emission inventories, as described above. Satellite observations of tropospheric ozone can be used as boundary conditions for regional air quality models. Although boundary layer ozone is difficult to measure from space, improvements in air quality forecasts of ozone potentially can be made through use of boundary conditions for the free troposphere derived from satellite. Satellite (OMI, GOME, GOME-2) observations of NO2 and HCHO can also be used to diagnose sensitivity of ozone production to NOx or VOCs (Martin et al., 2004).

(3) ***Surrogates for filling gaps in surface networks.*** Satellite observations are assisting the air quality community by providing data that covers broad spatial areas lacking ground based monitors and, more importantly, a vertical (or column) complement to surface based networks. Although 'breathing-zone' monitoring is essential, most pollutant mass resides outside the domain of surface stations. During well-mixed afternoon conditions in stable pressure systems, pollutant levels aloft often correlate well with surface conditions, offering potential for "gap filling" in the surface-based networks (Figure 4). However, the appeal of using satellite observations to fill gaps in surface measurement must be tempered by the limitations of using space based measurements to characterize near surface conditions discussed above. Use of this technique was illustrated by Al-Saadi et al. (2005).

(4) ***Support during episodes.*** Fire and dust events can produce atypically bad air quality in areas which do not typically experience poor air quality. Satellite data have played an important role in "exceptional event" analyses in the determination of attainment of National Ambient Air Quality Standards. Satellite data can act as a surrogate for gaps in surface monitoring data, and imagery can have an important public information role.

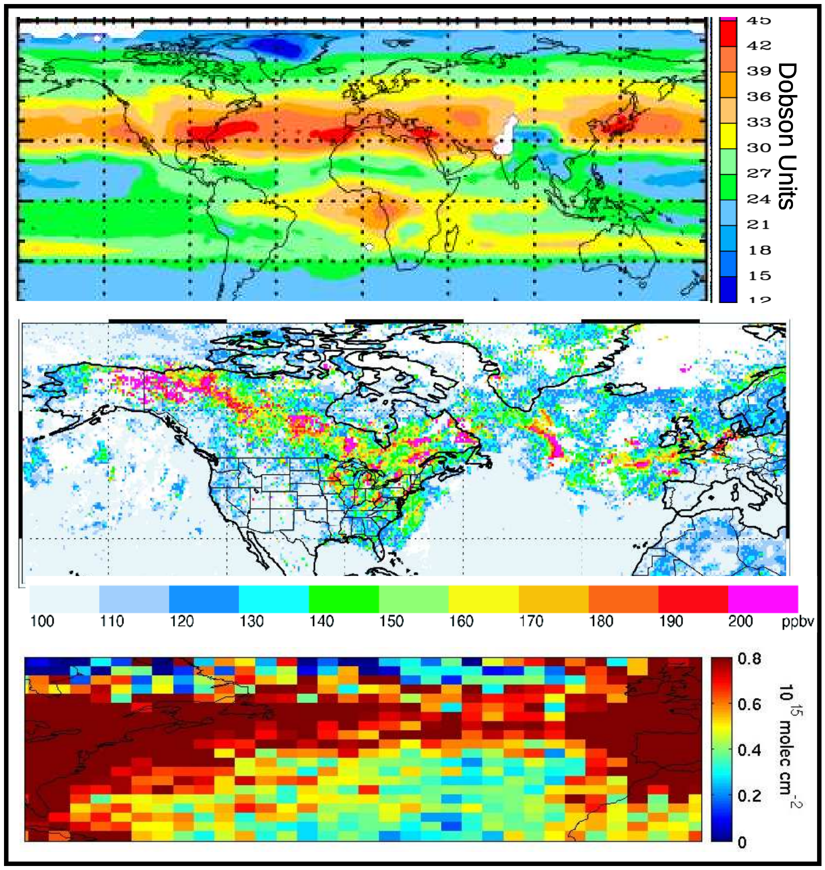

Figure 3. Panels capturing trans-Atlantic transport. Top: summer 1997 tropospheric ozone from GOME, (Liu et al., 2006). Middle: CO column totals from MOPITT for July 2004 (Pfister et al., 2005). Bottom: Tropospheric NO_2 from SCIAMACHY for summer 2004 (Martin et al., 2006).

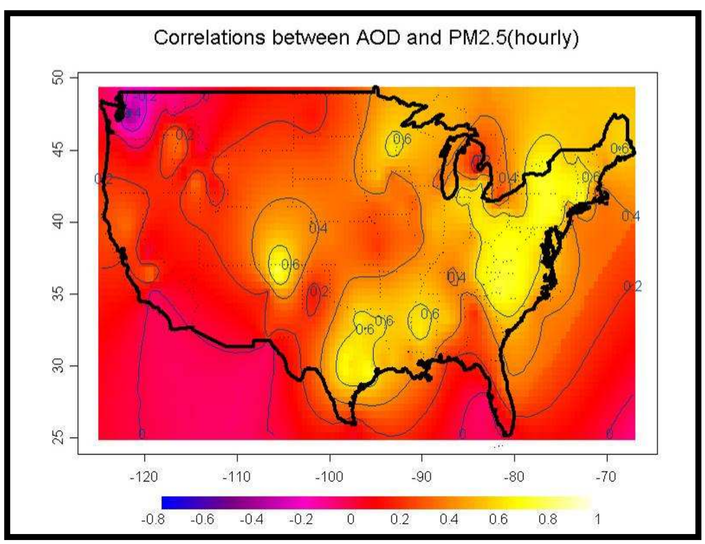

Figure 4. Correlation between MODIS AOD and hourly $PM_{2.5}$ surface sites from April - September, 2002 (Engel-Cox et. al, 2004).

2.4 Observation Programs for Climate, Background Concentrations, Stratospheric Ozone, and Long-Range Pollutant Transport

NOAA and NASA are the lead federal agencies for a variety of observation programs focused on climate change, background concentrations of trace gases in areas free of large local sources, stratospheric ozone, and pollutant transport. These networks include surface measurements, vertical profiling, and measurements of atmospheric columns (see Appendix H). The Department of Energy (DOE) is also engaged in observation programs addressing climate change. Many of these observation programs rely on partnerships across U.S. federal agencies and collaborations with international organizations such as the World Meteorological Organization (WMO). This section focuses on these networks in the U.S., which are largely the responsibility of NOAA, NASA and DOE, with various levels of participation through partner agencies. The assortment of gases and aerosols which are important climate moderators and/or key air quality indicator and precursor species include CO_2, N_2O, H_2O, CH_4, O_3, CO, aerosols, and halogenated compounds, including CFC replacements.

2.4.1. Greenhouse Gas (GHG) Observation Systems

NOAA, NASA, and DOE are lead Federal agencies for several programs, many in partnership with each other and with international organizations, which address greenhouse gas trends, sources, sinks, and fluxes. While these programs are focused on carbon dioxide budgets, the other important GHGs often are included where feasible. The major GHG observation programs with sites in the U.S. include:

NOAA global cooperative air sampling network -- Weekly samples from this cooperative network, which includes over 100 remotely located surface stations worldwide and a series of ship routes (Figure 8), are used to determine global CO_2, N_2O, CH_4, and CFC concentration trends.

AmeriFlux network -- DOE coordinates a multi-federal agency group (with NOAA, USDA, NSF) overseeing the AmeriFlux network of ~90 active sites in the U.S.; see Figure 8. The network sites are largely micrometeorological towers ranging from a few to hundreds of meters in height. Each tower is instrumented with a fast CO_2 monitor and wind sensor, allowing calculation the flux of CO_2 between the surface and vegetation and the atmosphere. AmeriFlux is a component of the worldwide Fluxnet system of CO_2 flux networks that track storage of carbon in terrestrial systems (http://www.fluxnet.ornl.gov/fluxnet/index.cfm).

Vertical profile, atmospheric column, and satellite observations -- The NOAA network of 8 tall towers (100 – 500 m) provides regionally representative near-continuous boundary layer measurements of CO_2 and related gases. As noted in section 2.3, NASA's Orbiting Carbon Observatory (OCO) satellite mission was intended to be the nation's primary remote sensing platform for CO_2 and to provide a continental and oceanic scale complement to ground based systems and aircraft programs. In light of OCO's 2009 launch failure, climate monitoring will rely on Japan's Greenhouse Gases

Observing Satellite (GOSAT), launched in January, 2009, which will measure CO_2 and CH_4 globally.

2.4.2. Monitoring of Background Air Quality and Long-Range Transport

Network of remote (sentinel) surface observation stations -- Remote surface stations located in areas relatively free from nearby sources characterize background pollutant levels, transport on regional and hemispheric scales, and boundary conditions for air quality models. NOAA maintains five baseline sites or surface "sentinel" stations (Mauna Loa, HI; Trinidad Head, CA; Barrow, AK; American Samoa; and South Pole) designed to capture long-term trends and atmospheric background air pollutant concentrations. These are part of a worldwide Global Atmospheric Watch (GAW) network of baseline sites coordinated by the WMO (Figure 5). Additional North American locations include Mt. Bachelor, OR; Whiteface Mountain, NY; and Alert in the Canadian Arctic.

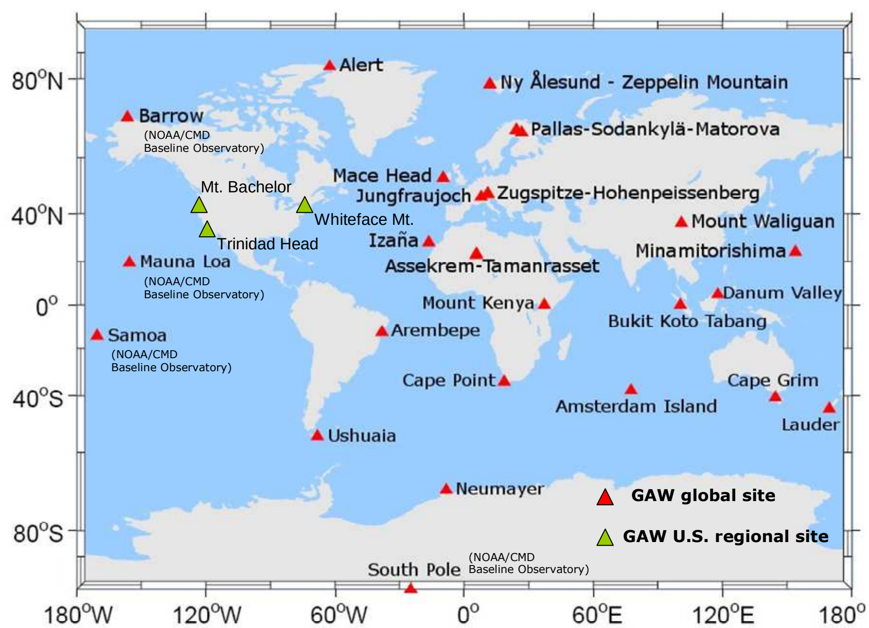

Figure 5. Network of surface based remote observatories organized through the World Meteorological Organization's Global Atmospheric Watch (GAW).

NASA fixed site observation networks -- The AGAGE (Advanced Global Atmospheric Gases Experiment - http://cdiac.ornl.gov/ndps/alegage.html), and its predecessors (the Atmospheric Life Experiment, ALE, and the Global Atmospheric Gases Experiment, GAGE) monitor a variety of climate forcing gases, CFCs and reactive trace gases at remote "sentinel" sites throughout the world.

2.4.3. Monitoring of Pollutants Aloft: Profiles and Total Columns

Vertical profiling and total atmospheric column measurements provide important complements to the near surface observations. Observations aloft provide insight into transport phenomena and background levels and are key metrics for model evaluation. Complex near-surface deposition and removal processes and micrometeorological processes limit the ability of surface-based measurements to characterize conditions aloft, except under certain conditions. Programs include a variety of aircraft, sondes, remote sensing, tall towers, and special field programs largely managed by NOAA, NASA, NSF and DOE. Proper siting and measurement techniques are used to produce observations which support assessments of climate change, stratospheric ozone, baseline concentrations, and long range transport. These approaches include sampling throughout the atmospheric column (for total column and vertical profiles) and, particularly for fixed surface observations, locations in relatively source free locations. While climate and stratospheric ozone depletion assessments benefit from characterizing the full atmospheric column through the stratosphere (~ 35 km), systems designed to capture the entire atmospheric column often have insufficient resolution or precision in the boundary layer (~ 5 km) for surface-oriented air quality assessments.

NOAA surface and aircraft based air quality measurement programs -- NOAA conducts a variety of routinely scheduled fixed-site and aircraft-based measurement programs and a series of intensive special field campaigns provide observations to address a variety of climate, stratospheric ozone depletion, and planetary boundary layer air quality issues. These programs are a source of data on conditions aloft. Core elements of these measurement programs include:

- an ozone radiosonde network (8 sites, 4 in the U.S.) provides one day per week vertical ozone profiles with approximately 100 m resolution from the surface through the stratosphere;

- Dobson ozone spectrometer network (16 station cooperative network, 11 in the U.S,) provides near continuous daytime total atmospheric column ozone data;

- routine aircraft flights that characterize vertical distribution of air pollutant species (O_3, CO, CH_4, CO_2, N_2O, SF_6) for climate and air quality assessments;

- tall tower sites (8) are part of the larger interagency North American Carbon Program (NACP) designed to characterize carbon sources, sinks and removal processes; these towers are currently located throughout the continental U.S. using television and cell phone towers (100 – 500 m tall). They provide near-continuous regionally representative boundary layer measurements of CO_2, CO, CH_4 and associated fluxes, various trace gases, and meteorological parameters (http://www.esrl.noaa.gov/gmd/ccgg/towers/index.html);

- special intensive studies, often in collaboration with NASA, with aircraft focusing on regional U.S. air quality issues, typically conducted every two years (section 2.2), and on satellite validation.

These programs, in combination with NOAA remote surface based measurement observatories (http://www.esrl.noaa.gov/gmd/about/airquality.html) provide long term records of baseline air quality from the surface through the stratosphere. These programs represent a substantial component of the U.S. contribution to international monitoring, much of which is organized through WMO's GAW program.

European based aircraft programs -- Two programs, MOZAIC (Measurement of Ozone, Water Vapor, Carbon Monoxide and Nitrogen Oxides Aboard Airbus In-Service Aircraft, operated since 1994) and CARIBIC (Civil Aircraft for the Regular Investigation of the Atmosphere Based on an Instrument Container, operated since 2004) measure air quality parameters from in-service, scheduled passenger aircraft based in Europe. These programs provide widely distributed, frequent measurements in the upper troposphere (including over the Atlantic) and, on takeoff and landing, vertical profiles over cities, including cities in North America. These programs provide the most extensive routinely-collected, vertically-distributed air quality data from throughout the troposphere.

MOZAIC: http://www.fz-juelich.de/icg/icg-ii/mozaic/home
CARIBIC: http://www.caribic-atmospheric.com/

Satellite air quality validation programs -- NASA oversees operations of several programs monitoring the lower atmosphere designed to complement and evaluate satellite products described in section 2.3. These programs generally have a broader hemispheric- or global-scale perspective that often overlaps with regionally focused initiatives.

Network for the Detection of Atmospheric Composition Change (NDACC) – The NDACC is an international activity focused on obtaining high quality measurements of a broad range of atmospheric chemical species and parameters. This network includes more than 70 remote-sensing research stations. Originally focused on the stratosphere, with an emphasis on the ozone layer, the scope of the NDACC has expanded to cover both the stratosphere and troposphere. A variety of working groups, each focused on a particular measurement or technique, operate under NDACC, including Dobson/Brewer, FTIR spectrometers, lidar, microwave radiometers, satellite measurements, sondes, UV/Vis spectrometers, spectral UV, and water vapor. This network has been in operation since 1991.

NDACC: http://www.ndsc.ncep.noaa.gov/

Lidar networks -- Lidar, analogous to radar, uses backscattered laser light to profile aerosols, gas-phase species, or other parameters such as temperature above a site. In addition to use during field intensives, there are three fixed-site, long-term lidar monitoring networks in the U.S. The Micro Pulse Lidar Network (MPLNET) is coordinated by NASA and operates from 14 stations (4 in the U.S.). MPLNET profiles aerosol, and most sensors are co-located with AERONET (see below). The NOAA CREST lidar network comprises four sensors, operated by academic institutions, in the eastern U.S., which profile aerosol. Three of these sites can also profile water vapor. Finally, the international Network for the Detection of Atmospheric Composition Change (NDACC, described above) includes 17 lidars (3 in the U.S.). These networks are affiliated with a number of networks operating overseas in the WMO / GAW Aerosol Lidar Observation Network (GALION).

2.4.4. Selected Meteorological Observation Systems

Two categories of above-surface meteorological systems are included here because of their linkage to air quality assessments. First, solar radiation networks provide estimates of atmospheric aerosols and various trace gases, in addition to basic data for radiation components of models. Second, systems that enable estimation of the height of the planetary boundary layer are important for near-surface air quality analyses and model applications.

Solar radiation networks -- Full spectrum and wavelength-specific solar radiation measurements provide data used to characterize energy budgets for meteorological models, climate change assessments, atmospheric column aerosol light scattering, and as direct indicators of UV radiation exposure relevant to human and ecosystem health and agriculture. A variety of federal agencies including NOAA, NASA, EPA, USDA and the NPS have participated in several measurement programs.

The Aerosol Robotic Network (AERONET) is a NASA-organized collaborative global network of sun photometers providing ground-based aerosol optical depth (AOD) estimates used primarily to evaluate satellite aerosol measurements. NOAA's Surface Radiation Budget Network (SURFRAD) is part of the global Base Line Surface Radiation (BASR) Network. It is an important surface complement to satellites, and is used for characterizing surface energy balances and supporting a variety of global scale climate models.

The Brewer UV spectrophotometer networks started in 1994 with EPA's UVNet program and included over 20 sites until funding was eliminated in 2004. A subset of six sites supported by EPA and NOAA is operating as the NOAA-EPA Brewer Spectrophotometer UV and Ozone Network (NEUBREW). These networks were designed to monitor UV radiation at the surface to understand its effects on human and ecosystem health and agriculture. Due to interest in the relationship between changes in stratospheric ozone and UV at the surface, EPA has provided some funding support. The Brewer instruments are capable of providing total column ozone and SO_2 estimates.

Observations for evaluating PBL heights -- Planetary boundary layer (PBL) height (or mixed layer height) is an important physical parameter in air quality models. PBL is a derived quantity based largely on vertical temperature profiles and refractive index structure parameters. The deployment of the NOAA Profiler Network (NPN: http://www.profiler.noaa.gov/npn/) over the last decade has added a near-continuous stream of wind vector data to complement the National Weather Service's (NWS) rawinsonde network, which provides twice daily soundings spread across nearly 100 locations throughout the United States. NPN consists of 35 unmanned Doppler radar sites profiling the troposphere, concentrated in the central United States, and is designed for violent weather forecasting. The PAMS (see section 2.1) program supports ~20 radar profilers that provide highly resolved wind profiles of the boundary layer. The boundary layer radar profilers, especially when complemented by temperature profiles generated by Radio-Acoustic Sounding System (RASS), offer a source of relatively untapped data for model evaluation.

In addition, cloud base height measurements from ceilometers are reasonable PBL depth indicators for non-clear sky conditions; a spatially extensive network for broad application is available through the NOAA Automated Surface Observing System (ASOS). In addition, since 2004, over 400 commercial aircraft have been collecting meteorological variables (temperature, pressure, RH, winds) as a part of the tropospheric Airborne Meteorological Data Reporting (TAMDAR - http://www.airdat.com/./tamdar/index.php) system. While TAMDAR is designed to provide near-real-time data for forecasting, the system provides valuable vertical profile temperature data (and other variables) during ascents and descents that potentially can be synthesized to fill in temporal and spatial gaps of ground based profilers.

The Meteorological Data Ingest System (MADIS - http://madis.noaa.gov/) is an integrated system incorporating observations from a variety of surface-based, vertical profile, and satellite networks.

3 Maintaining and Advancing Observation Programs

As discussed in the introduction, emerging challenges in air quality management will require pollutant monitoring programs to become both more comprehensive and more integrated. These improvements to the current monitoring infrastructure would enable substantial progress in meeting what has been identified as the “highest priority” goal in improving U.S. air quality management: strengthening the scientific and technical capacity of the air quality management system to assess risk and track progress (NRC, 2004). Addressing monitoring gaps and integrating observation systems help address what this National Academies panel listed as “critical actions”, including improving air quality monitoring, emissions estimates, and air quality models.

This section first outlines specific gaps in the current network (species, spatial, and temporal gaps) and describes how maturing satellite observations will complement existing networks, but will not fill those gaps. Next we describe how, beyond filling identified gaps, better integration of networks and between various types of data and models is needed to realize the full value of air quality monitoring data and the models that support air quality analysis. This integration is needed to meet the challenges identified above. Finally, we describe organizational barriers to advancement and integration of air quality monitoring networks.

3.1 Specific Gaps and Opportunities in Observation Systems

Network design is naturally based on the objectives of individual agencies and programs; this results in observational gaps that affect broadly integrated environmental assessments. Considering the complex issues described above, specific observational improvements would add considerable value to our system of air quality observations.

3.1.1 Measurement Gaps of Specific Species or Parameters

The following discussion summarizes observation needs advocated by the scientific community through NAS reports (NRC, 1991, 2004, 2009a,b), NARSTO assessments (NARSTO, 2003, 2010), and other venues.

These gaps significantly hamper analysis and assessment. For example, as a result of the lack of representative measurements, EPA’s model evaluation program does not routinely include comparisons between observations and models for a number of key species (e.g., CO, NO, and VOCs). These comparisons would be particularly useful indicators to evaluate the emissions, meteorology, chemical mechanism, transport parameterization, and other processes in the models.

<u>Nitrogen species.</u> Nitrogen chemistry plays an important role in a variety of environmental problems such as ozone, particulate matter, acidification, eutrophication, and visibility. Unfortunately, an adequate observation base does not exist to determine if ambient nitrogen response is consistent with measured and predicted NOx emissions changes in response to recent regulations. The ability of the existing urban-oriented measurement network to detect ambient NOx changes associated with regional scale emission reductions from power stations is compromised by strong local NOx emissions. Also, NO_2 data from most network NOx monitors is compromised by other oxidized nitrogen species. The NCore network will provide a modest contribution by measuring reactive nitrogen (NOy) in over 70 locations and should spur greater coverage and deployment of instruments producing true NO_2 observations. True NO_2 is an important diagnostic species for atmospheric chemistry processes and is needed to validate satellite NO_2 observations and convert column data into boundary layer concentrations. Accurate measurements of true NO_2 will also likely grow in importance if NO_2 NAAQS are tightened, causing the likelihood of nonattainment of the standard to increase.

Further measurements of oxidized nitrogen species, including peroxy acetyl nitrate (PAN) and nitric acid (HNO_3), would assist diagnosis of deposition and ozone production during transport. Increased use of biofuels will potentially elevate PAN concentrations, and along with observations of other carbonyl compounds, PAN will be an important indicator of the air quality impact of new fuels. Additionally, HNO_3 can be a key indicator species for understanding the NOx versus VOC limitation on ozone production in a given area.

Two reduced nitrogen species, gas-phase ammonia (NH_3) and particulate ammonium ion, are important components of nitrogen mass balance and important for assessments of visibility, fine particles, and ecosystem deposition. There are few ambient NH_3 measurements, as most monitoring of this species occurs in strong source (agricultural) locations to estimate emissions flux. Also, ammonium ion is analyzed as part of the chemical speciation program, but NH_3 volatilization creates a negative bias in those values.

Routine measurements at one or two representative locations of nitrate radical (NO_3), the dominant nighttime oxidizer, would enable diagnosis of model predictions of overall nitrogen characterization. Nitrous acid (HONO) is an important precursor of hydroxyl radicals (Stutz et al., 2004, Zhou et al., 2002) which are critical in daytime atmospheric chemistry. HONO also reacts heterogeneously with aerosols; HONO sources and chemistry are not well understood and are likely to be poorly characterized in air quality models.

Among these needs, a reasonable priority would be to enhance measurements of true NO_2 and NH_3 in our national networks.

CO and SO_2. The atmospheric lifetime of carbon monoxide (CO) of one to three months makes it a useful tracer for evaluating emissions and physical process approximations in air quality models. Sulfur dioxide (SO_2) is the predominant precursor of sulfate, which is a major contributor to PM, acid precipitation, and regional haze. The available SO_2 and CO measurements are largely urban and often in proximity to major sources, limiting their representativeness for broader areas. In addition, most of the current instruments were designed to capture high concentrations, for compliance purposes, and are not designed to measure the lower concentrations typical of rural areas.

Mercury. The chemistry of mercury in the atmosphere is unclear, but it is known that it has significant impacts on ecosystems and human health. MercNet is a planning effort organized through NADP to standardize and network multi-media mercury measurements. This network will combine existing and new monitors to the extent possible. Speciated mercury measurements are important for model evaluation and tracking progress of any future emission reduction strategies, although the existing technology will present challenges related to transitioning from research grade instruments to routine operations.

Volatile organic compounds. Biogenically generated VOCs (isoprene, terpenes, sesquiterpenes) contribute significantly to the formation of ozone and secondarily formed $PM_{2.5}$. These compounds are not monitored by the urban-based PAMS or toxics networks (see section 2.1), which are the primary sources of VOC data in the U.S. The absence of VOC data in most moderate-sized cities raises concerns regarding the overall representativeness of a network based primarily on the severity of ozone problems in the early 1990s. More troubling is the lack of rural VOC data, especially formaldehyde, which is a designated hazardous air pollutant (HAP) that is also used as a proxy for biogenic emissions and is a useful diagnostic for model evaluations. In addition, formaldehyde could indicate alterations in atmospheric chemistry resulting from a future transition to alternative transportation fuels (e.g., alcohols or natural gas). Finally, the value of total column formaldehyde from satellites would be enhanced by more spatially rich surface observations.

Organic PM composition. The organic carbon fraction of the total aerosol budget will increase given planned programs to reduce emissions of inorganic precursors from mobile sources and power plants combined with the large, uncontrollable organic emission from biogenic and biomass burning sources. Chemical speciation networks provide an aggregated total organic carbon estimate, since it is not practical to resolve the full molecular spectrum of organic aerosols. Nevertheless, key molecular markers (Schauer, 2005) would assist source apportionment and distinguishing primary and secondary aerosol. Given the cost of sample collection and analysis for organic composition, two to five diverse sites with representative mixes of aerosols and aerosol sources should be considered to supplement or replace current routine speciation analyses.

Aerosol physical properties. Interest in near roadway and ultrafine particle exposures, particle nucleation processes, and tracking change in aerosol size distributions associated with adoption of alternative transportation fuels (Wahlin et al., 2001) motivate improved particle property measurements. Recent advances in instrumentation that produce relatively reliable and low cost estimates of particle number and surface area offer potential for routine network operations. An initial two to four sustained sites to capture long term changes in particle size characteristics are recommended. Particle size measurements could be incorporated in a more focused effort characterizing a range of particle and gaseous attributes associated with the near roadway environments.

3.1.2 Spatial Gaps

Integrated assessments necessarily deal with the behavior of pollutants over multiple spatial scales, owing to the fact that physicochemical processes occur on overlapping scales of time and distance. Matching actual pollutant exposure to individuals, a key link in the source-to-outcome accountability chain, requires monitoring at a finer spatial scale than current networks provide. Primary emitted pollutants, which include most of the 188 designated HAPs as well as a significant fraction of PM, are subject to very dramatic gradients in the near-source region, which often coincides with high population density. Characterization of regional- to urban-scale pollutant gradients provides insight on the relative contribution of regional and local sources to local pollutant levels.

Juxtaposed with the need for finer-scale monitoring is an emerging understanding of long range transport and a gradual rising of background pollutant levels. The significance of these contributions to U.S. air quality is increasing, given the progress in North American pollution abatement, relative to increased atmospheric loading from expanding economies in Asia. Compounding the relative influence of transport and a rising background is the adoption of gradually more stringent U.S. air quality standards. Consequently, monitoring pollutant flow across North American borders, as well as global tracking of “background” levels, is relevant to North American multi-pollutant air quality management and accountability.

Spatial gaps in our observation networks include:

Near source - fine scale characterization. Ambient monitoring networks typically provide primary data to support a broad range of exposure, epidemiological, and risk assessment studies relating health outcomes to pollutant exposure. Epidemiological studies traditionally use air monitoring data from single, centrally-located urban stations as a surrogate of human exposure. However, (a) most people in North America live or commute in locations proximate to sources, especially roadways, and (b) pollutant gradients in urban environments create large uncertainties in outdoor exposure in large cities. Neither of these issues is addressed effectively in current monitoring programs.

Internal rural coverage. Three national level networks form the backbone of rural air quality measurements: IMPROVE, CASTNET and the NADP (see section 2.1). While these networks were designed for specific objectives, they have also been extremely useful for general air quality model evaluation and transport assessments. However, major spatial gaps exist in monitoring of surface-based ozone and key source indicator and precursor species (CO, SO_2, VOCs, speciated aerosol, NOx, and NOy) throughout the midsection of the nation (see Figure 2 in Section 2). EPA’s primary NAAQS, which are set to protect public health, have led to the urban focus in monitoring of these species. Rising background pollutant levels, and more stringent NAAQS, will require more focus on monitoring covering rural populations. Also, EPA is considering promulgation of one or more secondary NAAQS, to protect public welfare, that do not default to primary standards (as most have done over the last two decades). For example, inclusion of ecosystem-based critical load concepts into the formulation of a combined NOx/SO_2 secondary standard targeting acid deposition and eutrophication is under consideration.

Sentinel stations to link transport regimes. The addition of two or three remote stations on the east and west coasts of North America would support trans-oceanic transport assessments, global and regional air quality model evaluation, boundary conditions for models, and insight on trends of background air quality. Sentinel sites need to be supported by a stable resource base, since their most significant benefit is often derived from analyzing long-term trends. Coincident measurements of O_3 and aerosol components (nitrate, sulfate, organic and elemental carbon, trace metals), precursors of O_3 and aerosol (total reactive nitrogen, PAN, VOCs, and SO_2), and atmospheric tracers (such as CO, CO_2, and mercury) are needed. Transported pollution is mostly aloft, rather than at the surface. Such sentinel stations would be especially effective if they are located at altitude or if they include vertical profile measurements.

Vertical profiles of key atmospheric species. Vertical profiling of boundary layer and free troposphere air chemistry in North America is limited to lidar networks, specialized field campaigns, and a small number of ozone sonde releases. The CALIPSO instrument provides lidar profiles from space, producing several narrow "curtains" per day over the U.S. (although the boundary layer is often screened by clouds). More routine boundary layer profiling of meteorology and air chemistry would provide valuable support for model evaluation and emerging efforts integrating models and observations.

For example, surface-based networks typically monitor the lower ten meters of the atmosphere, where most of the air we breathe is located. However, there are usually significant differences between this air and the PBL, which models attempt to characterize, as a whole. In addition, the rawinsonde network lacks adequate temporal resolution to adequately track the diurnal patterns of PBL heights, while NPN radar profiling does not provide sufficient vertical resolution for PBL characterizations. Moreover, radar profilers have inadequate spatial coverage and lack consensus methodology to synthesize raw data into derived PBL heights conducive to model evaluation. Similar gaps were noted in a recent National Academies report on climate and weather observations (NRCb, 2009), which listed among the "highest priority observations needed to address current inadequacies" PBL height, air quality measurements above the PBL, and vertical profiles of humidity.

Since satellite total column data does not simply correspond to surface conditions, routine vertical profiles of key species such as ozone, NO_2, CO, SO_2, and aerosols are needed to establish the relationship between surface-based point and satellite observations, increasing the value of each system. As discussed below, this will help make satellite data appropriate to fill gaps in sparsely monitored areas. Potential investments in vertical profiling programs that would help leverage satellite data include:

- Expansion of NOAA's ozone sonde program to provide added spatial coverage in the continental U.S. and addition of key trace gas measurements.

- A sustained U.S.-based aircraft campaign (national and international flights), similar to the MOZAIC and CARIBE European efforts, to produce routine vertical profiles of key trace gases and aerosols.

- Deployment of fixed-site lidars at key locations throughout North America to provide continuous profiles of back-scattered light serving as a direct link between ground-based $PM_{2.5}$ in-situ samplers and MODIS and CALIPSO satellite instruments. Such a network could build on and complement the existing NDACC lidars and semi-routine aircraft-based measurements by NOAA.

3.1.3 Temporal Gaps

Temporal gaps in measurements include challenges in harmonizing continuous and gravimetric PM mass monitoring, and the lack of continuous or daily speciated particulate observations. As noted elsewhere, measurements from most satellites and sondes are only available once or twice per day, limiting their usefulness.

The demand for higher temporal resolution for particulate matter observations has increased as a result of recent findings regarding human health response (Peters et al., 2001) and with our developing understanding of multi-scale atmospheric processes. With the exception of PM mass, particle properties are not monitored continuously on most networks.

While North American networks have deployed over 500 routinely operating continuous $PM_{2.5}$ mass samplers, harmonization of continuous and gravimetric (i.e., federal reference) methods for PM mass remains a challenge. Measurement artifacts (e.g., loss of mass of semi-volatile constituents) associated with the filter-based, gravimetric techniques creates significant ambiguity in the PM data. Harmonization could make continuous data more comparable with gravimetric data, allowing characterization of particle concentration distributions across large areas, but could detract from efforts to produce “true” atmospheric aerosol measurements. Correlation techniques could avoid this problem. Eventually, harmonization of these measurements could address both temporal and spatial gaps in $PM_{2.5}$ monitoring.

Routine PM chemical speciation networks acquire 24-hour averaged samples, collected every third or sixth day. This sampling design is adequate for supporting the annual $PM_{2.5}$ standard and the U.S. regional haze program, but limits the investigation of PM associations with adverse health effects, evaluation of emissions, development of air quality models, and application of source attribution techniques. Continuous PM speciation technology has been used in the Supersites program, and light absorbing aethalometers (an indicator for elemental carbon) in the U.S. air toxics NATTS. Also, ten to twenty continuous sulfate and organic carbon analyzers are located in a mix of SEARCH and state or local agency platforms.

As noted above, atmospheric column and vertically resolved profiles of key air quality and meteorological observations typically lack adequate temporal resolution, in addition to a generally sparse spatial distribution. The twice-daily sonde launches often miss key periods of boundary layer evolution important for model evaluation. Polar orbiting satellites typically only provide one and sometimes two instantaneous readings per day for a specific location.

3.1.4 The Role of Satellite Observations

As surveyed in section 2.3, satellites provide nominally global daily monitoring of a number of species important for air quality and climate. The important limitations of these measurements were discussed above. Here we discuss how satellites can complement other monitoring, emphasizing that both types of observation become more valuable when they are integrated.

Satellites observe air quality where little or no routine in-situ monitoring occurs, such as over oceans and rural areas. Low Earth orbit missions provide near-global coverage, with limited temporal resolution and coverage. Geostationary missions offer much better temporal coverage of a defined region.

Current and future air quality satellite missions provide a stream of air quality information for North America, and should strongly influence design of our routine monitoring programs. These data will improve near-term air quality characterizations and offer potential to enhance air quality assessments; however, considerably greater value is realized from satellite observations when integrated with complimentary ground-based point and vertical profile observations. This begins with the validation effort, when the algorithms used to produce column densities from raw satellite readings are refined and calibrated; validation depends on independent measurements underneath the satellite. Several of the surface-based recommendations for trace gas measurements, such as formaldehyde, NO_2, CO, and SO_2, discussed above would be very helpful for validation. Intensive field studies have been useful in providing vertical information for satellite validation, but they have limited temporal and spatial coverage.

Beyond that stage, satellite data become useful for addressing spatial or temporal gaps in ambient monitoring when integrated with existing monitoring networks. This would enhance both regional and global scale air quality characterizations, addressing important criteria pollutants such as O_3 and $PM_{2.5}$ and selected air toxics such as formaldehyde. The integration of these disparate measurements is discussed below in section 3.2.

In addition to the challenges and limitations of using satellite data discussed above, it is organizationally challenging for EPA to effectively support planning and development of satellite missions. This is discussed in section 3.3.

3.2 Integration Opportunities and Approaches

In light of the challenges described in section 1, assessment of many air quality problems is best served by the use of many types of observations and models. Likewise, these observations serve multiple objectives, and are needed by disparate organizations and user communities. Integration of observations of different types, and from different organizations, is a major opportunity, but also a significant challenge.

Conceptually straightforward integration opportunities, from a variety of perspectives, include:

- Enhancing the horizontal and vertical characterization of key species:
    - horizontally by combining urban- and rural-based networks (e.g., urban-based speciation networks with the rural-based IMPROVE program; SLAMs (urban) and CASTNET (rural) O_3 stations)
    - vertically through the atmospheric column by blending surface measurements, vertically-resolved observations from ground-based and aircraft platforms, and satellite data
- Combining precipitation and dry observation networks to develop deposition fields, as performed currently through the CASTNET and NADP programs
- Collocating atmospheric deposition observations with soil and surface water measurement campaigns
- Collocating a variety of different species measurements to yield multiple pollutant characterizations within a consistent spatial frame
- Matching ambient measurement fields to human activity patterns to estimate exposures, and matching ambient measurements to emissions fields, via inverse modeling, to refine emissions estimates
- Using air quality models in combination with observations to address spatial and temporal gaps associated with limited observations**.**

Some of these examples are straightforward like-to-like combinations of two networks with different but overlapping domains. Others, such as blending of satellite, surface, and aircraft data, or combinations of models with observations, are technically and scientifically challenging. Finally, organizational barriers (see section 3.3.) exist for all of these, particularly those that require moving monitors or modifying methods.

3.2.1 Observations and Models to Improve Environmental Characterization

Increasingly, models and observations are being used together, in a variety of ways, due to advances in computational efficiencies and in response to the complexities discussed in Section 1. Air quality models typically have been used in prognostic applications that address hypothetical questions considering the effects of management programs and rules on future emissions and air quality changes – a function outside the scope of observations. More recently, air quality models have been used for forecasting (next day) air pollution and providing more spatial texture beyond central site monitors to drive human exposure models. Observations themselves lack adequate resolution (space, time, and composition) to support integrated assessments.

The integration of chemical observations and chemical transport models is evolving and shares common attributes with weather characterization (and forecasting), although lagging in maturation. Observation and model integration efforts range from using measurements to evaluate model performance to four dimensional data assimilation (FDDA), as used in meteorological models. Variations and intermediate levels of integration exist. Areas of model-observation linkages include:

- Model results to guide monitoring site design for placement in areas of expected high concentrations, steep concentration gradients, and important transport corridors;

- Observations supplying direct inputs for initial and/or boundary conditions;
- Observations to indirectly improve model inputs through inverse modeling of emissions;
- Observations to evaluate model performance, diagnose model behavior and constrain model adjustments;
- Observations combined or "fused" with model estimates to add spatial, temporal and compositional texture to air quality gradients; and
- Dynamic assimilation of observations to nudge model estimates, analogous to FDDA in meteorological systems.

These linkages between models and observations are emphasized here to influence a shift in monitoring design that explicitly recognizes the relationships of observations to models.

3.2.2 Information Technology to Facilitate Data Access, Integration and Use

Integrated air quality management requires technology to facilitate discovery, access, manipulation, archiving, and harmonization of numerous disparate information sources. Accessing and manipulating observations from single networks or databases remains a challenge, despite large investments. Some applications and tools to access and integrate multiple data systems have eased the integration of disparate data from multiple programs, but by and large differing formats and standards and gaps in metadata significantly hamper integration of different types of data and models. This prevents analysts from realizing the full value of air quality data.

The EPA system for accessing air quality observations was designed primarily as a repository for data and covers only a part of U.S. observational archives. Several other organizations have recently built publicly accessible, user-friendly air quality data reduction, integration, analysis, and visualization systems. These include VIEWS, the Visualization Information Exchange Web System developed by the Regional Planning Organizations (RPOs) in support of visibility assessments, and the Health Effects Institute's air quality database (see section 2.1). NARSTO (http://www.narsto.org/) also has constructed an accessible database for intensive field campaigns.

GEOSS, the Global Earth Observation System of Systems (see section 1.3), is a current effort to build a framework to enable national governments to make Earth science data more accessible and usable for decision support. GEOSS is designed to make data easier to find and access, but also to support a service-oriented, interoperable, systems approach, in contrast with the end-to-end systems typically built to process, manipulate, and visualize air quality and satellite data. This approach should produce more cost-effective, nimble, and usable tools to allow analysts to integrate different types of monitoring data, models, emissions inventories, etc. The GEOSS approach has been demonstrated and piloted by several projects, with some support from federal agencies. These include:

- DataFed (http://datafedwiki.wustl.edu/index.php/DataFed_Wiki), which demonstrates linking surface-based air quality data integration systems such as VIEWS with observational and modeling systems, expanding the range of environmental characterization relevant to comprehensive integrated environmental assessments.

- Air Quality work in the 2008 – 2009 GEOSS Architecture Implementation Pilot, which developed the GEOSS infrastructure for air quality data and built "Air Quality Community Infrastructure" which air quality analysts can use as an interface with GEOSS. https://sites.google.com/site/geosspilot2/air-quality-and-health-working-group

These emerging integrated systems will help address technology needs for comprehensive assessments, but will require a substantial, sustained investment and engagement from supporting and user communities.

3.3 Barriers to Progress

Any approach to addressing the emerging air quality and assessment issues must recognize the resource, technological, and institutional constraints that impede the progress of air quality monitoring programs.

Sustaining infrastructure. As is well documented in many fields, it is challenging for organizations to maintain infrastructure. Monitoring systems are similar. Users are often in different organizations than providers and take the data for granted. In fact, seamless, automated access to data lets users work with data with minimal awareness of who produced it. Many measurement networks struggle with outdated technology, old equipment, and aging workforces. Monitoring systems support more visible downstream assessments, and often rely on "trickling down" of resources, which is difficult to sustain.

Organizational priorities. Organizations often lack the resource flexibility to support medium or low priority measurements. For example, EPA relies on Federal Reference Methods (FRM) and Federal Equivalent Methods (FEM) to assess compliance with air quality standards. With constrained budgets, other measurements of strong scientific value generally are difficult to fund. Recent EPA examples include the continued acceptance of existing NOx instruments with known biases, despite development of a new NO_2 standard.

Transitioning research and technology development to operations. Measurement programs supported by research organizations are particularly vulnerable to loss of funding, compromising long-term records and other applications. In the case of satellites, "research" sensors/platforms with finite lifetimes are typically not replaced. Although analysis of long-term air quality patterns is a research interest, research organizations typically focus on methods development and physicochemical process characterization and expect to transition routine measurement programs to operational organizations. For example, NASA satellite missions typically have defined operational time spans, yet transition to longer term operational status through partner agencies is generally not planned in advance. Successful transitions have included the LANDSAT mission partnership between USGS and NASA, as well as EPA's management of CASTNET, which was transitioned from EPA's research office to EPA's air office in the late 1990s.

The original NCore monitoring strategy for proposed Level 1 sites was to form partnerships between universities and state and local agencies to test emerging instrumentation and jointly share in the transition of research grade equipment to operations. Despite recommendations from EPA's Science Advisory Board, Level 1 deployment has not been developed beyond the conceptual stage. Consequently, for example, there has been inadequate incorporation of continuously operated speciated particulate matter and mercury, and inorganic nitrogen species (reduced and oxidized forms).

Challenges of Long-Term Support for Future Satellite Missions

A particular case of the research-to-operations challenge is the difficulty user agencies face supporting the development and funding of future satellite missions. Satellite instruments are planned, developed, and funded years before the platform is launched, due partly to the high costs associated with satellite missions. This time frame often extends beyond the planning time horizon of a regulatory agency. EPA does not fund satellite missions, but it would be useful for it and other user agencies to have a mechanism to express support for instruments / missions and commit to using the data they produce. While it is difficult for an operational agency to commit to use data many years in the future, such commitments will influence mission funding and instrument design decisions.

Satellite instruments have proven to be essential for air quality analysis and management. Moving forward, to respond to demands from emerging air quality assessment challenges, satellite data will continue to be critical, a message that needs to be conveyed by user agencies.

Market incentives. Beyond the need for FRM/FEM instruments, there are few market incentives for instrumentation firms to pursue the engineering and development steps required to produce operational grade methods. This financial barrier is linked to the above noted issues regarding agency priorities, transition from research to operations, and communications.

Observation technology is typically developed by individual research groups for specific applications typically associated with a specific lab or field campaign objective; this technology can then be passed on to other users. For example, NASA develops satellite observation platforms in space and on aircraft typically for single use, promising technologies are then transferred to NOAA and satellite sensors are operationalized by NESDIS. There is no similar development path for surface monitoring technologies for atmospheric chemistry for use by EPA or state and local air quality managers.

4 Recommendations

4.1 Establish a Standing Multi-Agency Observations Working Group

The survey of air quality observations and the analysis presented in this report has pointed to a number of deficiencies and opportunities for improvement in the air quality observation system as currently implemented in the U.S. The report also identifies a number of generic recommendations to address these deficiencies.

The authors recommend the establishment of a working group on air quality observations, to be chartered under the Air Quality Research Subcommittee of the CENR, to address these deficiencies. The objectives of this working group would be:

- Provide a forum to facilitate cooperation and collaboration among the federal agencies with air quality observation programs. Air quality measurements are important to so many users that a broader view of the health, relevancy, and evolution of observation programs should complement the existing single-organization focus on discrete network elements.
- Provide an interface between the various user communities [e.g. air quality managers, health scientists, air quality forecasters, etc.] and those involved in making air quality observations to insure the benefits are maximized for both communities.
- Extend the analysis presented in this report and develop specific recommendations for improvements to the Nation's air quality observing system and track progress towards the goals established. Specifically, the Working Group on Air Quality Observations would:
    - assess the adequacy of current networks and measurement technologies
    - identify important measurement gaps
    - identify important information gaps and opportunities for advancing technology and sharing and utilization of observation programs.
- Coordinate the development of multi-agency initiatives to address deficiencies that have been identified and enhance and extend air quality observations in the US.

The issues raised in Section 3 would constitute the subject area for this working group. The unique contribution of this group, relative to interagency review mechanisms, would be an emphasis on a comprehensive, integrated scope that is missing from single agency perspectives. The task force would conduct periodic reviews of the U.S. air quality observation system, assessing the ability to meet current and anticipated needs. Key gaps in measurements that would provide important benefits in combination with existing programs would be identified, as well as inefficiencies such as redundant or outdated programs. Building on coordination and collaboration themes, the task force would promote information technology efforts that enhance data access, discovery, interoperability, understanding, and usefulness, recognizing the benefits of multiple users in realizing the full value of observations and providing important quality assurance feedback. In addition to this programmatic coordination, the task force would identify opportunities for development of measurement technologies.

Key to the success of this group is the ability to provide meaningful input to the allocation process for both existing and planned resources. The involvement of federal agencies engaged in air quality observing programs (e.g., EPA, NOAA, NASA, USDA, DOE, DOI) should be considered. Given the unlikelihood of any clear authority granted to a multi-agency working group, a charter must be developed clearly articulating responsibilities of the group members and chains of communications and methods to effect needed change in observations programs. Options, which are not mutually exclusive, include direct reporting to agency senior management and resource officials, briefings for National Academy of Science officials and relevant committees, and consideration of approaching the appropriate Congressional committees and advisory bodies to the Administration (e.g., Council on Environmental Quality (CEQ), Committee on Environmental and Natural Resources Research (CENR), Office of Science Technology and Policy (OSTP), etc.).

4.2 Address Current Observation Gaps

Numerous important measurements that are missing or in short supply were described in Section 3. This analysis will need to be revisited as monitoring systems and our understanding of the atmosphere evolve, and it will be appropriate for the task force to add their perspective to the analysis presented there.

While requests for added observations have been raised periodically, this renewed effort is intended to (a) increase the overall value-to-cost ratio incurred collectively through a system of measurement programs and (b) improve the comprehensive effectiveness of measurement programs where past requests have focused on specific topics without recognition of the broader opportunities for leverage and cooperation. Suggested steps include:

1. initiate monitoring of reactive gas and particulate nitrogen compounds, which are precursors of ozone and particulate matter, contributors to acid deposition, and nutrients in ecosystems,
2. collocate instrumentation at core monitoring sites to facilitate inter-comparison with satellite observations,
3. expand monitoring in rural/remote areas to measure regional backgrounds and contributions from long-range transport of pollutants,
4. establish monitoring in near-source areas to track trends and better understand observed near-source health effects, and
5. expand intensive field studies designed to elucidate critical processes that determine atmospheric concentrations of ozone and particulate matter and other air pollutants.

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Introduction to Appendices for Existing Air Quality Monitoring Programs

Observation programs supporting air quality and related assessments include routine regulatory networks, deposition networks, intensive field studies, remote sensing systems, sondes, aircraft campaigns, satellites, and focused fixed-site special purpose networks. Appendices A – H provide information on a wide variety of these air monitoring networks. Major networks that are currently operating are emphasized; reference to other networks that have been discontinued, or that were only intended for a specific operating period, is also provided. The focus is on networks located in the U.S., but attention is also given to other North American, European and international efforts that contribute to U.S. assessments.

Given the emerging themes in the main body of the report stressing integration of spatial scales, environmental media and pollutant categories, the scope of coverage providing an overview of networks is inclusive. While fixed-site, surface-based networks constitute the majority of coverage, programs providing total Earth column and vertical-profile, remote-sensing systems and dedicated vertical profiling programs are also widely used. Programs addressing climate forcing gases and aerosols, long range transport and assessment of stratospheric ozone complement the more traditional regulatory-oriented networks; they are included with the intention of exploring effective methods toward integration of the various networks to serve multiple purposes.

The information in these appendices is generally organized by measurement category covering a range of networks and programs:

Appendix A. Evolution of United States Air Monitoring Networks
Appendix B. Major Routine Operating Air Monitoring Networks
Appendix C. National Routine Meteorological Monitoring Networks
Appendix D. European Air Monitoring Networks
Appendix E. Monitoring Networks for Persistent Organic Pollutants (POPs)
Appendix F. Field Campaigns for Non-Routine Special Intensive Studies
Appendix G. Satellite - Based Air Quality Observing Systems
Appendix H. Air Monitoring Networks for Climate Forcing, Transport, Vertical Profile Information, and Stratospheric Ozone
Appendix I. Acronyms

Appendices are generally provided in table-form that includes the network name, lead agency, number of monitoring sites, the year initiated, measurement parameters (primarily air pollutants and meteorological parameters), and the Internet address for information and/or data for the network identified. Limited supplemental information is given in tables for the non-routine special intensive studies and for the satellite observing systems.

Information provided in the appendices is the product of extensive Internet searches and information provided by knowledgeable representatives of the agencies responsible for the networks. In most cases, the information provided has been taken directly from the referenced Internet site; this is particularly true of supplemental information for the non-routine special intensive studies. Attribution of this information should be to those Internet websites.

The appendices, in addition to providing a useful reference or starting point for discussion in the body of the report, also provide a basis for addressing needed air monitoring network enhancements, whether they be for additional parameters, site locations in key rural gaps and source areas, or added vertical information. While the appendices provide only a limited factual synopsis of the air monitoring networks and data that may be available, they do provide a start for the more analytical process of identifying the value that is and is not provided by the networks. Ideally, these catalogs of monitoring networks should form a basis for assessment, i.e., the redundancies, the gaps, and the effectiveness of networks in meeting intended objectives. Such an assessment sets the stage for recommendations in the main body of this report.

Information for and comments on preliminary versions of the monitoring network tables were provided by:

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Appendix A. Evolution of United States Air Monitoring Networks

The 1970 Clean Air Act (CAA) established a framework for the original National Ambient Air Quality Standards (NAAQS) and drove the design and implementation of the NAMS and SLAMS networks in the late 1970s. These networks were intended primarily to establish non-attainment areas with respect to the NAAQS which include ozone, sulfur dioxide, nitrogen dioxide, carbon dioxide, lead and particulate matter (PM). The NAMS/SLAMS networks have evolved over time (Figure A.1) as a result of cyclical NAAQS review and promulgation efforts leading to changes in measurement requirements related to averaging times, locations and the various size cuts associated with PM.

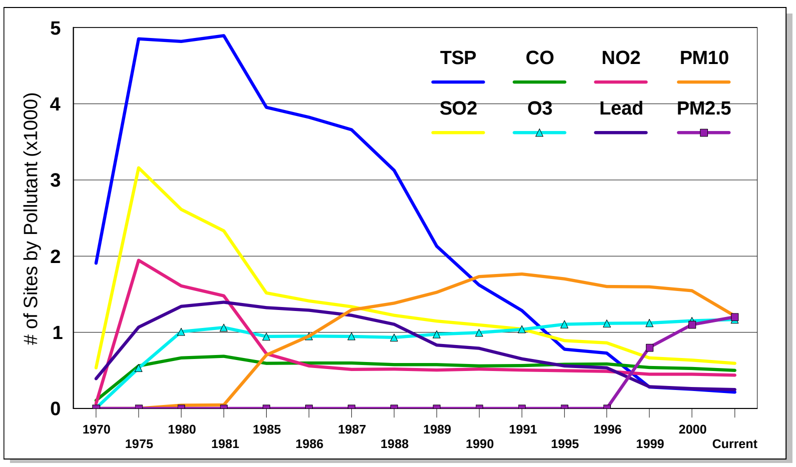

Figure A.1. Evolution of U.S. air network growth.

Relatively wide geographical distribution and persistence of ozone and $PM_{2.5}$ NAAQS exceedances (Figure A.2) have lead to these pollutants dominating the national monitoring landscape.

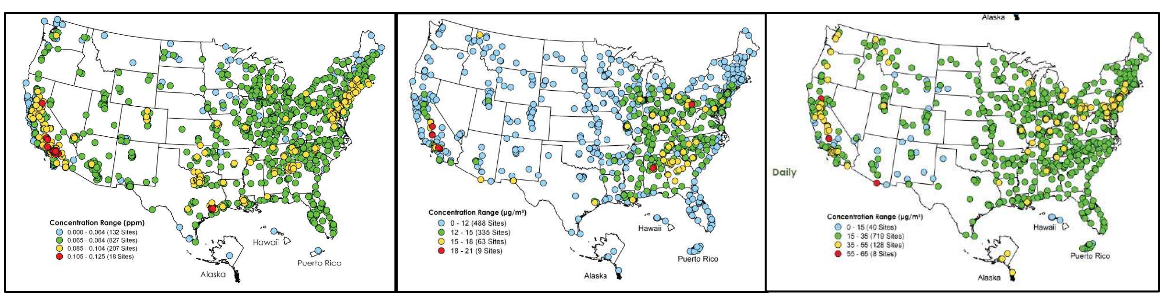

Figure A.2. 2006 air quality summaries for ozone, annual average PM2.5 and daily PM2.5. Yellow and red sites indicate values excceeding NAAQS levels (source, EPA).

Two important ambient air networks focused on environmental welfare effects were established in the mid-1980’s. The Interagency Agency Monitoring of Protected Visual Environments (IMPROVE) network with over 100 sites in National Parks and other remote locations is used primarily to assess visibility impairment, but has provided a reliable long term record of PM mass and major speciation components and served as a model for the later deployment of EPA's STN network (see Figure 2 of full report), which has provided an urban complement to characterize aerosol composition (Figure A.3).

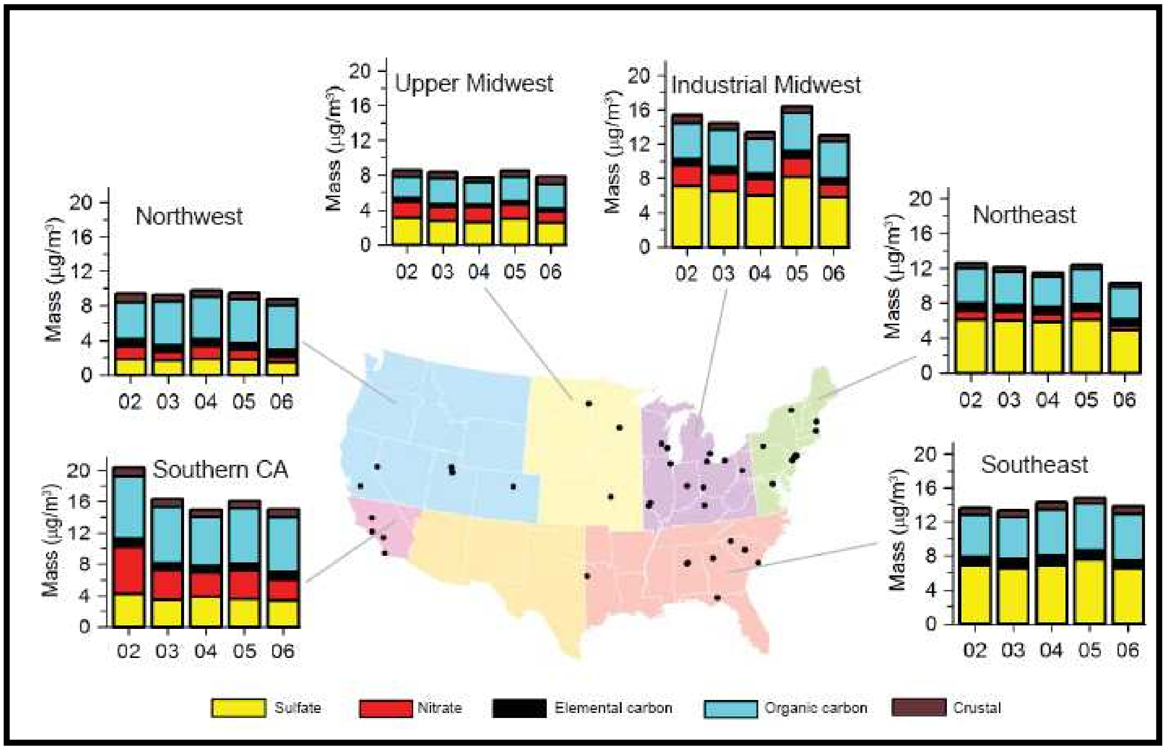

Figure A.3. Regional chemical composition of $PM_{2.5}$ aerosols based on urban speciation sites and averaged over the entire 2006 sampling period (source, 2006 EPA Air Quality Trends Report).

The Clean Air Status and Trends Network (CASTNET) was established in the early 1990s to track changes in dry deposition of major inorganic ions and gaseous precursors associated with the CAA Title 4 reductions in sulfur and nitrogen, designed to address surface water acidification in Eastern North America. Complementing ongoing precipitation measurements from the National Atmospheric Deposition Program (NADP), CASTNET has provided a valuable source of model evaluation data for many of the large regional scale applications since the 1990's.

Deployment of the Photochemical Assessment and Measurements Stations (PAMS) and the $PM_{2.5}$ networks from the early 1990's through 2002 markedly enhanced the spatial, temporal and compositional attributes of gases and aerosols, partially supporting user needs beyond NAAQS compliance (e.g., public reporting and forecasting of adverse air quality; implementation efforts including air quality model evaluation and source apportionment and pattern (spatial and temporal) analysis of precursor species.

State and local air agencies have measured a variety of metallic and gaseous hazardous air pollutants (HAPs) at over 200 locations since the 1980's. Typically, broad access and use of those data were compromised by a lack of centralized data bases and multiple sampling and laboratory protocols enhancing data uncertainty. In response to this gap in accessible and centralized HAPs observations, a modest 23 site National Air Toxics Trends (NATTS) network was initiated in 2001. Current NATTS species include: Acrolein, Perchloroethylene, Benzene, Carbon tetrachloride, Chloroform, Trichloroethylene, 1,3-butadiene, 1,2-dichloropropane, Dichloromethane, Tetrachloroethylene, Vinyl chloride, Formaldehyde, Acetaldehyde, Nickel compounds, Arsenic compounds, Cadmium compounds , Manganese compounds,, Beryllium, Lead, Hexavalent chromium, and expected additions of Benzo(a)pyrene, Napthalene.

A new multiple pollutant monitoring network referred to as NCore was incorporated in the 2006 revisions to the particulate matter standards. When finally implemented in 2009, NCore will provide a minimum of 75 Level 2 sites (Figure A.4) in most major urban areas and important transport corridor and background locations. NCore will include a variety of trace gas, aerosol mass and speciation measurements which are intended to support multiple data user needs (e.g., air quality model evaluation, long term epidemiological studies). In addition to establishing a multiple pollutant measurement framework, the NCore sites are intended to provide a backbone of central location sites that can be complemented by additional (existing and new) stations to address more specific spatial resolution requirements. A lack of funding support has hindered implementation for more intensive Level 1 sites, intended to promote transition of new technologies into routine networks, which were endorsed by the monitoring subcommittee of the Clean Air Scientific Advisory Committee (CASAC).

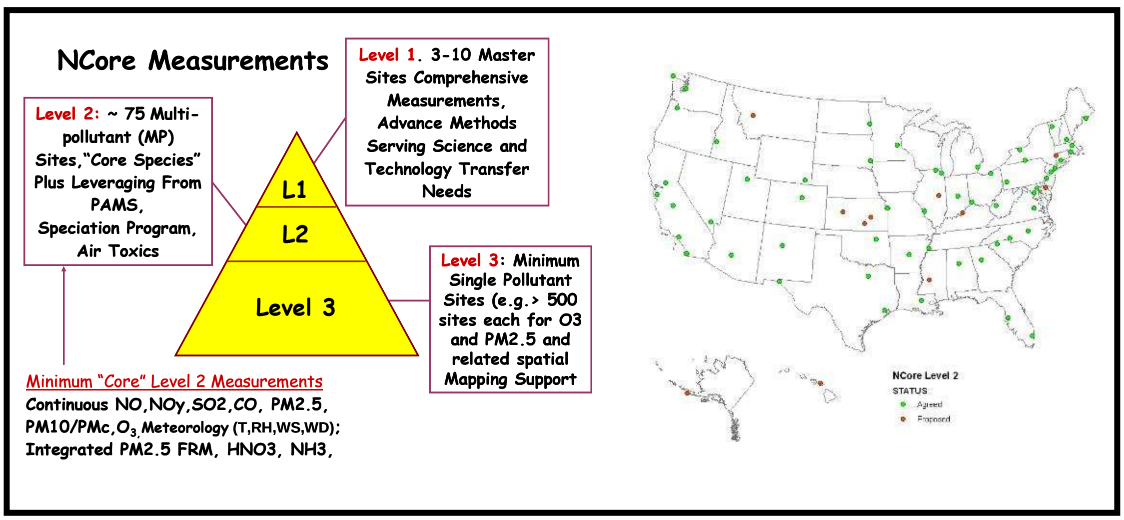

Figure A.4. Original 3-tiered NCore design (left) and proposed site locations

APPENDIX B. MAJOR ROUTINE OPERATING AIR MONITORING NETWORKS[4]

Network	Lead Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
State / Local / Federal Networks					
NCore[1] – National Core Monitoring Network	EPA	75	2008	O3, NO/NO2/NOy, SO2, CO, PM2.5/PM10-2.5[2], PM2.5 speciation, NH3, HNO3, Surface Meteorology[2]	http://www.epa.gov/ttn/amtic/monstratdoc.html
SLAMS[1] – State and Local Ambient Monitoring Stations	EPA	~3000	1978	O3, NOx/NO2, SO2, PM2.5/PM10, CO, Pb	http://www.epa.gov/air/oaqps/qa/monprog.html
STN—PM2.5 Speciation Trends Network	EPA	300	1999	PM2.5, PM2.5 speciation, Major Ions, Metals	http://www.epa.gov/ttnamti1/specgen.html
PAMS—Photochemical Assessment Monitoring Network	EPA	75	1994	O3, NOx/NOy, CO, Speciated VOCs, Carbonyls, Surface Meteorology & Upper Air	http://www.epa.gov/air/oaqps/pams/
IMPROVE—Interagency Monitoring of Protected Visual Environments	NPS	110 plus 67 protocol sites	1988	PM2.5/PM10, Major Ions, Metals, Light Extinction, Scattering Coefficient	http://vista.cira.colostate.edu/IMPROVE/
CASTNet – Clean Air Status and Trends Network	EPA	80+	1987	O3, SO2, Major Ions, Calculated Dry Deposition, Wet Deposition, Total Deposition for Sulfur/Nitrogen, Surface Meteorology	http://www.epa.gov/castnet/
GPMN—Gaseous Pollutant Monitoring Network	NPS	33	1987	O3, NOx/NO/NO2, SO2, CO, Surface Meteorology, (plus enhanced monitoring of CO, NO, NOx, NOy, and SO2 plus canister samples for VOC at three sites)	http://www2.nature.nps.gov/air/Monitoring/network.cfm#data
POMS—Portable Ozone Monitoring Stations	NPS	14	2002	O3, surface meteorology, with CASTNet-protocol filter pack (optional) sulfate, nitrate, ammonium, nitric acid, sulfur dioxide	http://www2.nature.nps.gov/air/studies/portO3.cfm
Passive Ozone Sampler Monitoring Program	NPS	43	1995	O3 dose (weekly)	http://www2.nature.nps.gov/air/Studies/Passives.cfm
NADP/NTN—National Atmospheric Deposition Program / National Trends Network	USGS	200+	1978	Major Ions from precipitation chemistry	http://nadp.sws.uiuc.edu/
NADP/MDN—National Atmospheric Deposition Program / Mercury Deposition Network	None	90+	1996	Mercury from precipitation chemistry	http://nadp.sws.uiuc.edu/mdn/
AIRMoN—National Atmospheric Deposition Program / Atmospheric Integrated Research Monitoring Network	NOAA	8	1992	Major Ions from precipitation chemistry Note: some sites began in 1976 as part of the DOE MAP3S program; early data are archived on NADP and ARL servers.	http://nadp.sws.uiuc.edu/AIRMoN/
IADN—Integrated Atmospheric Deposition Network	EPA	20	1990	PAHs, PCBs, and organochlorine compounds are measured in air and precipitation samples	http://www.epa.gov/glnpo/monitoring/air/
NAPS—National Air Pollution Surveillance Network	Canada	152+	1969	SO2, CO, O3, NO, NO2, NOx, VOCs, SVOCs, PM10, PM2.5, TSP, metals	http://www.etc-cte.ec.gc.ca/NAPS/index_e.html
CAPMoN—Canadian Air and Precipitation Monitoring Network	Canada	29	2002	O3, NO, NO_2, NO_y, PAN, NH_3, $PM_{2.5}$, PM_{10} and coarse fraction mass, PM2.5 speciation, major ions for particles and trace gases, precipitation chemistry for major ions	http://www.msc.ec.gc.ca/capmon/index_e.cfm
Mexican Air Quality Network	Mexico	52-62	Late 1960's	O3, NOx, CO, SO2, PM10, TSP,VOC	http://www.ine.gob.mx/dgicur/calaire/indicadores.html
Mexican City Ambient Air Quality Monitoring Network	Mexico	49	Late 1960's	O3, NOx, CO, SO2, PM10, TSP,VOC	http://www.ine.gob.mx/dgicur/calaire/indicadores.html

APPENDIX B. MAJOR ROUTINE OPERATING AIR MONITORING NETWORKS[4] (continued)

Network	Lead Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
Air Toxics Monitoring Networks					
NATTS—National Air Toxics Trends Stations	EPA	23	2005	VOCs, Carbonyls, PM10 metals[3], Hg	http://www.epa.gov/ttn/amtic/airtoxpg.html
State/Local Air Toxics Monitoring	EPA	250+	1987	VOCs, Carbonyls, PM10 metals[3], Hg	http://www.epa.gov/ttn/amtic/airtoxpg.html
NDAMN—National Dioxin Air Monitoring Network	EPA	34	1998 - 2005	CDDs, CDFs, dioxin-like PCBs	http://cfpub.epa.gov/ncea/CFM/recordisplay.cfm?deid=54811
Tribal Monitoring Networks					
Tribal Monitoring[5]	EPA	120+	1995	O3, NOx/NO2, SO2, PM2.5/PM10, CO, Pb	http://www.epa.gov/air/tribal/airprogs.html#ambmon
Industry / Research Networks					
New Source Permit Monitoring	None	variable	variable	O3, NOx/NO2, SO2, PM2.5/PM10, CO, Pb	Contact specific industrial facilities
HRM Network—Houston Regional Monitoring Network	None	9	1980	O3, NOx, PM2.5/PM10, CO, SO2, Pb, VOCs, Surface Meteorology	http://hrm.radian.com/houston/how/index.htm
ARIES / SEARCH—Aerosol Research Inhalation Epidemiology Study / SouthEastern Aerosol Research and Characterization Study experiment	None	8	1992	O3, NO/NO2/NOy, SO2, CO, PM2.5/PM10, PM2.5 speciation, Major Ions, NH3, HNO3, scattering coefficient, Surface Meteorology	http://www.atmospheric-research.com/studies/SEARCH/index.html
SOS – SERON—Southern Oxidant Study - Southeastern Regional Oxidant Networks	EPA	~40	1990	O3, NO, NOy, VOCs, CO, Surface Meteorology	http://www.ncsu.edu/sos/pubs/sos3/State_of_SOS_3.pdf
National/Global Radiation Networks					
RadNet—formerly Environmental Radiation Ambient Monitoring System (ERAMS)	EPA	200+	1973	Radionuclides and radiation	http://www.epa.gov/enviro/html/erams/
SASP -- Surface Air Sampling Program	DHS	41	1963	^{89}Sr, ^{90}Sr, naturally occurring radionuclides, ^{7}Be, ^{210}Pb	http://www.eml.st.dhs.gov/databases/sasp/
NEWNET—Neighborhood Environmental Watch Network	DOE	26	1993	Ionizing gamma radiation, Surface Meteorology	http://newnet.lanl.gov/
Solar Radiation Networks					
UV Index – EPA Sunrise Program[6]	EPA	~50 U.S. cities	2002	Calculated UV radiation index	http://www.epa.gov/sunwise/uvindex.html
UV Net -- Ultraviolet Monitoring Program	EPA	21	1995/2004	Ultraviolet solar radiation (UV-B and UV-A bands), Irradiance, ozone, NO2	http://www.epa.gov/uvnet/access.html
NEUBrew (NOAA-EPA Brewer Spectrophotometer UV and Ozone Network)[7]	NOAA	6	2005	Ultraviolet solar radiation (UV-B and UV-A bands), Irradiance, ozone, SO_2	http://www.esrl.noaa.gov/gmd/grad/neubrew/

APPENDIX B. MAJOR ROUTINE OPERATING AIR MONITORING NETWORKS[4] (continued)

Network	Lead Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
Solar Radiation Networks (continued)					
UV-B Monitoring and Research Program	USDA	35	1992	Ultraviolet-B radiation	http://uvb.nrel.colostate.edu/UVB/index.jsf
SURFRAD – Surface Radiation Budget Network	NOAA	7	1993	solar and infrared radiation, direct and diffuse solar radiation, photosynthetically active radiation, UVB, spectral solar, and meteorological parameters	http://www.srrb.noaa.gov/surfrad/index.html
AERONET – Aerosol RObotic NETwork MPLNET – Micro-pulse Lidar Network	NASA co-located networks	22 + other participants 8	1998 2000	Aerosol spectral optical depths, aerosol size distributions, and precipitable water Aerosols and cloud layer heights	http://aeronet.gsfc.nasa.gov/index.html http://mplnet.gsfc.nasa.gov/
PRIMENet -- Park Research & Intensive Monitoring of Ecosystems NETwork[7]	NPS	14	1997	ozone, wet and dry deposition, visibility, surface meteorology, and ultraviolet radiation	http://www.cfc.umt.edu/primenet/Assets/Announcements/99PReport.pdf

Footnotes:

1. NCore is a network proposed to replace NAMS, as a component of SLAMS; NAMS are currently designated as national trends sites.
2. Surface Meteorology includes wind direction and speed, temperature, precipitation, relative humidity, solar radiation (PAMS only).
3. PM10 metals may include arsenic, beryllium, cadmium, chromium, lead, manganese, nickel, and others.
4. Some networks listed separately may also serve as subcomponents of other larger listed networks; as a result, some double counting of the number of individual monitors is likely.
5. The number of sites indicated for tribal monitoring is actually the number of monitors, rather than sites. The number of sites with multiple monitors is probably less than 80.
6. Sunrise program estimates UV exposure levels through modeling - does not include measurements.
7. NEUBREW is a subset Original UV brewer network (UV Net); PRIMENET participated in UV Net program.

APPENDIX C. NATIONAL ROUTINE METEOROLOGICAL MONITORING NETWORKS

Network	Lead Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
ASOS -- Automated Surface Observing System	NOAA	~1000 (supplemented by military weather observation sites)	1992 (replaced routine surface observations collected manually at 260 Weather Service facilities)	Continuous measurements of: Wind Direction and Wind Speed; Visibility; Runway Visual Range; Type, intensity and amount of rain, snow, etc.; Obstructions due to fog, mist, etc.; Cloud Height and Amount; Ambient Temperature; Dew Point Temperature; Pressure; Lightning detection; Automated, manual, and plain language remarks on special weather conditions (depending on level of service); and Additive and automated maintenance data on precipitation amount, max/min temperature, pressure tendency, etc.	http://www.nws.noaa.gov/asos/pdfs/aum-toc.pdf
Cooperative Observer Program	NOAA	~11,400	1890	24-hour maximum and minimum temperatures, Liquid equivalent of precipitation, snowfall, snow depth, and Other special phenomena such as days with thunder, hail, etc.	http://www.nws.noaa.gov/om/coop/coopmod.htm
SLAMS – State and Local Ambient Monitoring Stations	EPA	~3000	1978	Wind direction and speed, Temperature, Precipitation, Relative humidity	http://www.epa.gov/air/oaqps/qa/monprog.html
Remote Automated Weather Stations	DOA	~2200	~1978	Wind direction and speed, Precipitation, Pressure, Temperature, Relative humidity, Fuel moisture and temperature	http://www.fs.fed.us/raws/raws101.shtml
NOAA Profiler Network (and Cooperative Agency Profilers)	NOAA	35 (plus ~100 CAP sites)	1992	Vertical profiles of wind direction and speed (and vertical profiles of temperature at RASS sites)	http://www.profiler.noaa.gov/npn/
Upper Air Stations (Weather Balloons)	NOAA	102 in North America, Pacific Islands, and the Caribbean	1937	Measurements of temperature, relative humidity, wind direction and speed, and altitude/height at selected pressure levels.	http://www.ua.nws.noaa.gov/net-info.htm
Forecast Systems Laboratory Aircraft Communications Addressing and Reporting System	NOAA	~4000 commercial aircraft	2001 (routinely available database)	Wind direction, wind speed and temperature reported for various altitudes at which aircraft typically operate	http://acweb.fsl.noaa.gov/FAQ.html#variables
National Doppler Radar Sites	NOAA	158	1990 (national radar network originated prior to 1960)	Base Reflectivity, Composite Reflectivity, One-Hour Precipitation, and Storm Total Precipitation	http://www.srh.noaa.gov/radar/radinfo/radinfo.html
National Lightning Detection Network	Commercial	100+	1989	Detection of cloud-to-ground lightning flashes at distances up to 400 km	http://www.nwstc.noaa.gov/METEOR/Lightning/detection.htm
National Environmental Satellite, Data, and Information Service	NOAA	2 GOES satellites 2 POES satellites	1994 (earlier satellite systems replaced)	Vertical profiles of temperature, moisture, and wind; visible and infrared imagery of clouds; water vapor imagery	http://www.goes.noaa.gov/
C-MAN – Buoy and Coastal-Marine Observing Network	NOAA	70	Early 1980s	Pressure, wind direction, wind speed and gust, and air temperature, relative humidity, precipitation, visibility, sea water temperature, water level, and waves	http://www.ndbc.noaa.gov/cman.php

APPENDIX D. EUROPEAN AIR MONITORING NETWORKS

Network	Lead Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
EMEP – Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (encompasses networks for ~37 European countries and organizations)	UNECE	270	1977	**Acidifying / Eutrophying Compounds** (precipitation): SO4, NO3, NH4, trace elements, pH, acidity (air): SO2, NO2, HNO3, NH3, PM10, PM2.5, major ions **O3** **Heavy Metals** precipitation, major ions, PM2.5, PM10, Hg, wet deposition **POPs** precipitation, air, deposition **Particulate Matter** PM2.5, PM10, EC, OC, TC, BC **VOC** Hydrocarbons, Carbonyls	http://www.nilu.no/projects/ccc/emepdata.html
EUROTRAC – The European Experiment on the Transport and Transformation of Environmentally Relevant Trace Constituents over Europe	International Executive Committee (European Countries)	???	1986	EUROTRAC programs performed analyses utilizing data from existing or specially designed monitoring networks in order to: 1. elucidate the chemistry and transport of ozone and other photo-oxidants in the troposphere, e.g., TOR -- 30 O3 stations and ALPTRAC -- 15 snow monitoring sites 2. identify processes leading to the formation of acidity in the atmosphere, particularly those involving aerosols and clouds. 3. understand uptake and release of atmospheric trace substances by the biosphere.	http://www.gsf.de/eurotrac/index_what_is.html
EUROTRAC-2 -- The EUREKA project on the transport and chemical transformation of trace constituents in the troposphere over Europe; second phase. Subprojects: – AEROSOL – BIATEX-2 – CAPMAN – CMD – EXPORT-E2 – GENEMIS – GLOREAM – LOOP – MEPOP – PROCLOUD – SATURN – TOR-2 – TRAP45 – TROPOSAT	International Scientific Secretariat (European Countries and EU)	???	1996	EUROTRAC-2 programs performed analyses utilizing data from existing monitoring networks in order to: support the further development of abatement strategies within Europe by providing an improved scientific basis for the quantification of source-receptor relationships for photo-oxidants and acidifying substances.	http://www.gsf.de/eurotrac/index_what_is.html

APPENDIX E. MONITORING NETWORKS FOR PERSISTENT ORGANIC POLLUTANTS (POPs)

Network	Lead Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
Global Monitoring of Persistent Organic Pollutants (POPs)[1]	UNEP – United Nations Environment Programme	N/A	2003	Activities include developing guidance on sampling and analysis of POPs, QA/QC procedures, data treatment and communication and data assessment. In addition the programme will include an electronic discussion group on POPs monitoring issues where existing programs and laboratories are invited to participate and share their experience on this subject.	http://www.chem.unep.ch/gmn/default.htm
AMAP – Artic Monitroing and Assessment Programme	NOAA (as U.S. representative to the 8 nation Artic Council)	???	~1991	Air/aerosol sampling for POPs, heavy metals, radioactivity and acidification parameters; bulk precipitation and snowpack sampling to estimate deposition[2]	http://www.amap.no/
EMEP -- Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe	UNECE – United Nations Economic Commission for Europe	17	1991	Benzo(a)pyrene, PCBs, hexachlorobenzene, Chlordane, lindane, hexachlorocyclohexane, DDT/DDE in precipitation and gas particles	http://www.chem.unep.ch/gmn/012_emep.htm
GAPS – Global Atmospheric Passive Sampling	UNEP – United Nations Envrionment Programme	50	2004	12 chemicals including Aldrin, Chlordane, DDT, Deldrin, Endrin, Heptachlor, Hexachlorobenzene, Mirex, PCBs, Dioxins(PCDDs), Furans(PCDFs), Toxaphene and other pollutants	http://pubs.acs.org/cgi-bin/article.cgi/esthag/2004/38/i17/html/es040302r.html
NDAMN – National Dioxin Air Monitoring Network	EPA	34	1998 - 2005	CDDs. CDFs, dioxin-like PCBs	http://cfpub.epa.gov/ncea/CFM/recordisplay.cfm?deid=54811
IADN -- Integrated Atmospheric Deposition Network	EPA	20	1990	PAHs, PCBs, and organochlorine compounds are measured in air and precipitation samples	http://www.epa.gov/glnpo/monitoring/air/
EMAP – Environmental Monitoring and Assessment Program	EPA	12,600	1988	Oriented to ecological and water monitoring	http://www.epa.gov/emap/index.html

APPENDIX F. FIELD CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES[3,4]

Network	Lead Agency[1]	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data	Notes
CalNex 2010	NOAA (with CARB & CEC)	1 ship, 2 aircraft	2010	Primary pollutants (CO, NO, NO2, SO2, NMHC, CO2, NH3, PM, VOC, black carbon, and greenhouse gases); Secondary species: O3, CH2O, aldehydes, PAN, HNO3, NO3, N2O5, sulfuric acid, hydroxyl and peroxy radicals, aerosol size distribution and chemical composition; Other parameters (H2O, aerosol properties, radiation, and meteorological paramenters).	http://www.esrl.noaa.gov/csd/calnex/whitepaper.pdf	This is to be a joint field study of atmospheric processes over California and the eastern Pacific coastal region that emphasizes the interactions between air quality and climate change issues, including those affecting the hydrologic cycle. The study will constitute one of a series of comprehensive regional air quality and climate assessments conducted by NOAA with expansion of CARB's leadership of California air quality studies. It will complement the ongoing CEC regional climate change studies and will bring together specialized, complementary resources such that the outcome will be able to address important scientific questions that have an impact on environmental policy. Airborne (NOAA WP-3D Orion, NOAA Twin Otter Remote Sensing Aircraft), ship (NOAA R/V Ronald H. Brown), on-going ground-based instrument packages (upper-air observations, ground-based chemical measurements), and satellite observations (MODIS, GOES) will be employed. The collaboration of agencies will link short-term data gathered during the field program to extensive surface observations, long term data sets, and California's advanced modeling capabilities for both regional air quality and climate.
Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS / POLARCAT)	NASA (with various universities & research institutions)	3 aircraft 1 monitoring site	2008 (spring / summer)	Primary pollutants (CO, NO, NO2, SO2, NMHC, CO2, NH3, PM, VOC, black carbon, and greenhouse gases); Secondary species: O3, CH2O, aldehydes, PAN, HNO3, NO3, N2O5, sulfuric acid, hydroxyl and peroxy radicals, aerosol size distribution and chemical composition; Other parameters (H2O, aerosol properties, radiation, and meteorological parameters)	http://www.polarcat.no/activities/nasa-arctas/arctas_wp.pdf & data workshop	ARCTAS is a study of the impact of air pollution and forest fires on the arctic climate that integrates measurements from multiple aircraft and satellites. It has four major scientific themes: (1) long range transport of pollution to the Arctic including arctic haze, tropospheric ozone, and persistent pollutants such as mercury; (2) boreal forest fires and their implications for atmospheric composition and climate; (3) aerosol radiative forcing from arctic haze, boreal fires, surface deposited black carbon, and other perturbations; and (4) chemical processes with focus on ozone, aerosols, mercury, and halogens. ARCTAS is part of a larger interagency and international IPY effort collectively identified as POLARCAT which is intended to execute a series of aircraft experiments following pollution plumes as they are transported into the Arctic.
Texas Air Quality Study II (2005 - 2006)	Texas	17	2006	O3, NOx, NOy, SO2, Haze, Visibility, CO, VOC, Solar Radiation, Surface Meteorology, Upper Air	http://www.utexas.edu/research/ceer/texaqsII/PDF/12-12-04_Projected_Surface Sites_tbl.pdf	Researchers from universities, state and federal agencies, private industry, and local governments are joining forces to conduct a major field study to address air quality issues in the eastern half of Texas. The study, planned for a period extending from April 2005 through October 2006, will examine regional ozone formation, transport of ozone and ozone precursors, meteorological and chemical modeling, issues related to ozone formation by highly reactive emissions, and particulate matter formation. It is anticipated that the information from the study will be the scientific basis used for developing State Implementation Plans (SIPs) for ozone (with concentrations averaged over 8 hours), regional haze, and, if necessary, for fine particulate matter (particulate matter less than 2.5 microns in diameter, $PM_{2.5}$

APPENDIX F. FIELD CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES (continued)

2006 Texas Air Quality Study/ Gulf of Mexico Atmospheric Composition and Climate Study (TexAQS/GoMACCS)	NOAA	1 ship, 2 aircraft	2006	O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters & upper air	http://esrl.noaa.gov/csd/2006/	For TexAQS 2006, the NOAA air quality component will investigate, through airborne and sea-based measurements, the sources and processes that are responsible for photochemical pollution and regional haze during the summertime in Texas. The focus of the study will be the transport of ozone and ozone precursors within the state and the impact of the long-range transport of ozone or its precursors.
Intercontinental Chemical Transport Experiment - North America (INTEX-B) -- Intercontinental Transport and Chemical Transformation (ITCT/IGAC)	NOAA	3 aircraft	2006	O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters, altitude -- NOAA aircraft	http://cloud1.arc.nasa.gov/intex-b/	The export of air pollutants from urban to regional and global environments is a major concern because of wide-ranging potential consequences for human health, cultivated and natural ecosystems, visibility degradation, weather modification, changes in radiative forcing, and tropospheric oxidizing capacity. During the spring of 2006 a highly integrated atmospheric field experiment was performed over and around North America. The Megacity Initiative: Local and Global Research Observations (MILAGRO), http://www.eol.ucar.edu/projects/milagro/, resulted through a highly coordinated collaboration between NSF (through MIRAGE-Mex), DOE (through MAX-Mex), NASA (through INTEX-B) and a variety of research institution in the U.S. and Mexico and involved ground and air borne activities centered on Mexico City, Mexico during March 2006. MILAGRO goals were greatly facilitated and enhanced by a number of concurrent and coordinated national and international field campaigns and global satellite observations. After MILAGRO, NASA continued investigating this issue, this time focusing on the influence of Asian pollutants on North America, through a second airborne field element of INTEX-B in collaboration with NSF and NCAR. The integrated goals of MILAGRO and INTEX are: -To study the extent, persistence, and transformation of Mexico City pollution plumes; -To relate atmospheric composition to sources and sinks; -To quantify radiative properties and effects of aerosols, clouds, water vapor & surfaces; -To map anthopogenic and biogenic emissions; -To characterize transport and evolution of Asian pollution to North America and beyond and determine implications for regional air quality and climate; -To achieve science-based validation of satellite observations of troposheric composition
International Consortium for Atmospheric Research on Transport and Transformation (ICARTT)	NOAA (with various other agencies and research institutions)	Multiple aircraft and other measurement platforms	2004	Surface sites and networks, mobile platforms (aircraft and ship) and satellite data were used for measurement parameters; see http://www.esrl.noaa.gov/csd/ICARTT/fieldoperations/ for detailed information	http://www.esrl.noaa.gov/csd/ICARTT/index.shtml	ICARTT was formed to study the sources, sinks, chemical transformations and transport of ozone, aerosols and their precursors to and over the North Atlantic Ocean. Groups in North America and Europe had independently developed plans for field experiments in the summer of 2004 that shared many of the same goals and objectives in overlapping study areas; the plans were aimed at developing a better understanding of the factors that shape air quality in their respective countries and the remote regions of the North Atlantic. ICARTT was formed to take advantage of this synergy by planning and executing a series of coordinated experiments to study the emissions of aerosol and ozone precursors and their chemical transformations and removal during transport to and over the North Atlantic. The combined research conducted in the programs that make up ICARTT focus on **regional air quality**, **intercontinental transport**, and **radiation balance** in the atmosphere.

APPENDIX F. FIELD CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES (continued)						
Intercontinental Chemical Transport Experiment - North America (INTEX-NA) -- Intercontinental Transport and Chemical Transformation (ITCT/IGAC)	NOAA	aircraft, sondes, satellites	2004	O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters, altitude -- NOAA aircraft	http://cloud1.arc.nasa.gov/intex-na/desc.html	INTEX-NA is an integrated atmospheric field experiment performed over and around North America. It seeks to understand the transport and transformation of gases and aerosols on transcontinental/intercontinental scales and their impact on air quality and climate. A particular focus in this study is to quantify and characterize the inflow and outflow of pollution over North America. The main constituents of interest are ozone and precursors, aerosols and precursors, and the long-lived greenhouse gases. INTEX-NA is part of a larger international ITCT (Intercontinental Transport and Chemical Transformation) initiative. INTEX-NA goals are greatly facilitated and enhanced by a number of concurrent and coordinated national and international field campaigns and satellite observations. Synthesis of the ensemble of observations from surface, airborne, and space platforms, with the help of a hierarchy of models is an important goal of INTEX-NA.
New England Air Quality Study (NEAQS) -- Intercontinental Transport and Chemical Transformation (ITCT) 2004	NOAA	4 site, 1 ship, 2 aircraft, profiler network	2004	O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters & upper air	http://esrl.noaa.gov/csd/2004/	NOAA continues a joint regional air quality and climate change study combining elements of the previous NEAQS study and the Intercontinental Transport and Chemical Transformation (ITCT) research activity to focus on air quality along the Eastern Seaboard and transport of North American emissions into the North Atlantic. The major NOAA assets (the two aircraft and the ship) are deployed in a manner that supports the objectives of both components.
East Tennessee Ozone Study (ETOS)	NOAA	15+	2003	O3, Surface Meteorology	http://www.arl.noaa.gov/etos_122005.php	ETOS 2003 developed a regional ozone database to include both mean hourly averages and hourly histograms of individual measurement readings. The 2003 study period (based on scoping studies 1999 - 2002) provides a regional view to supplement Tennessee's regulatory network and serves as a demonstration and evaluation/validation database for various operational and developmental air quality forecast model components. The full scope of ETOS 2000 is continuously under planning and review, and is refined each year using the previous year's analysis and experience to focus on particular issues within the East Tennessee region.
Texas Air Quality Study (TexAQS) 2000	Texas	~20	2002	O3, NOx, PM2.5/PM10, CO, SO2, VOCs, Surface Meteorology	http://www.utexas.edu/research/ceer/texaqs/visitors/about.html	The study is designed to improve understanding of the factors that control the formation and transport of air pollutants along the Gulf Coast of southeastern Texas. Six weeks of intensive sampling, including measurements of gaseous, particulate, and hazardous air pollutants, are made at approximately 20 ground stations, located throughout the eastern half of the state. Experts in meteorology, atmospheric chemistry, and other areas of science study the formation, composition, and day-night cycles of ozone and particulate matter, as well as how these pollutants are affected by weather.
Texas Air Quality Study (TexAQS) 2000 Field Campaign	NOAA	2 aircraft	2002	O3, CO, CO2, SO2, NO, NO2, NOy, PAN, HNO3, NH3, VOCs, Solar Radiation, Meteorological Parameters, aerosols	http://www.utexas.edu/research/ceer/texaqs/visitors/about.html	Additional sampling in TexAQS 2000 is carried out with specially equipped aircraft that can detect air pollutants very quickly, at very low concentrations.

APPENDIX F. FIELD CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES (continued)

Bay Region Atmospheric Chemistry Experiment (BRACE)	NOAA	1 aircraft	2002	NO3, NH4, O3, SO2, NOx, CO, trace metals, particulates	http://www.dep.state.fl.us/secretary/news/2002/02-039.htm	The Florida Department of Environmental Protection (DEP), with the support of a team of federal, state, local, university and private scientists (including NOAA) conducted a month-long series of intensive studies to determine the level of influence of nitrogen deposited into Tampa Bay from local and regional sources of air pollutants on water quality. During the Bay Region Atmospheric Chemistry Experiment (BRACE), NOAA operated a research aircraft over the Tampa Bay region to collect air quality measurements of the many atmospheric forms of nitrogen and related pollutants that may potentially influence the water quality of Tampa Bay.
New England Air Quality Study (NEAQS) 2002 -- AIRMAP	NOAA	4	2002	O3, NOx, NOy, SO2, CO, VOCs, PM2.5, Precipitation Chemistry, Surface Meteorology	http://airmap.unh.edu/data/	AIRMAP is a research program focused on atmospheric chemical and physical observations in rural to semi-remote areas of New Hampshire with the goal of understanding inter-relationships in regional air quality, meteorology, and climatic phenomena. Research goals are to: (1) document and analyze current trends in the regional air quality of New England which is affected by transport from upwind regions of the U.S. and Canada and by local emission sources; (2) document and analyze current and past (the last 100 years) synoptic-to-local meteorological patterns, features, and extreme events in New England; and (3) numerically simulate the coupled evolution of atmospheric transport and chemistry in New England using various modeling tools.
New England Air Quality Study (NEAQS) 2002	NOAA	1 ship, 2 aircraft	2002	O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters & upper air	http://esrl.noaa.gov/csd/NEAQS/	The NOAA component of this multi-institutional effort addresses the analysis of existing climate data, and the development of new air quality monitoring programs. A background of information is to be developed that addresses New England's changing climate and air quality so as to improve understanding of the relationship between air quality and weather and determine the causes of climate change in New England
Intercontinental Transport and Chemical Transformation (ITCT) 2002 Activities	NOAA	1 site, 1 aircraft	2002	CO2, CO, CH4, SO2, O3, SF6, N2O, CFCs, Aerosols, Solar Radiation, Surface Meteorology & Upper Air -- surface. O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters & upper air -- aircraft	http://esrl.noaa.gov/csd/ITCT/2k2/	This field program, scheduled for spring 2002 to investigate the composition of air masses along the Pacific coast of North America, is part of the Intercontinental Transport and Chemical Transformation (ITCT) research activity of the International Global Atmospheric Chemistry Program (IGAC) Program. Goals of this field study are to: characterize the chemical composition of the air masses coming ashore at the West Coast; explore the composition of these air masses as they are transported inland; and investigate the alteration in composition associated with the addition of emissions from U.S. West Coast sources. The NOAA WP-3D aircraft is to deploy a wide array of instrumentation for the in situ measurement of gaseous and aerosol parameters plus radiation and remote aerosol sensing by LIDAR. The Trinidad Head baseline observatory characterizes chemical composition of marine boundary layer at the U.S. West Coast and provides linkage between composition measurements and radiative properties of the aerosols. The NOAA ETL Laboratory network of 915-MHz radar wind profilers that are deployed in California provide additional meteorological information.

APPENDIX F. FIELD CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES (continued)

TRAnsport and Chemical Evolution over the Pacific (TRACE-P)	NASA	2 aircraft	2001 (2 months)	O3, NO, NO2, N2O, CH4, SO2, NH3, CO, CO2, aerosols, PAN, HNO3, aldehydes, peroxides, speciated hydrocarbons, other pollutants, meteorological parameters	http://www-gte.larc.nasa.gov/gte_fld.htm#TRACE	TRACE-P is part of a series of aircraft missions aimed at better understanding of global tropospheric chemistry, and more specifically in this case, the effects of outflow from the Asian continent on the composition of the global atmosphere. Objectives are to determine: (1) pathways for outflow of chemically and radiatively important gases and aerosols, and their precursors, from eastern Asia to the western Pacific; and (2) the chemical evolution of the Asian outflow over the western Pacific, and the ensemble of processes that control this evolution. Approximately 20 aircraft measurement flights involving horizontal and vertical profiles for a total of over 300 hours were supported by surface based measurements and soundings.
Aerosol Characterization Experiments - Asia (ACE-Asia)	NSF	sites, ships, aircraft, satellites	2001 (spring)	aerosol chemical, physical, and radiative properties and radiative fluxes, meteorological parameters	http://saga.pmel.noaa.gov/Field/aceasia/ACEAsiaDescription.html	The Aerosol Characterization Experiments (ACE) are designed to increase understanding of how atmospheric aerosol particles affect the Earth's climate system. ACE-Asia took place during the spring of 2001 off the coast of China, Japan and Korea which includes many types of aerosol particles of widely varying composition and size. These particles include those emitted by human activities and industrial sources, as well as wind-blown dust. Data from ACE-Asia is improving understanding of how atmospheric aerosols influence the chemical and radiative properties of the Earth's atmosphere.
Central California Ozone Study (CCOS)[2]	California	100+ sites, 6 aircraft, profilers, sondes	2000	O3, VOC, NOx, NO, NOy, CO, PM10, PM2.5, solar radiation, surface meteorology, upper air	http://www.arb.ca.gov/airways/	For the summer season, this study collected meteorological and air quality data for the central section of California in 2000. Planes and weather balloons collected data at ground level and aloft. The data collected is used to improve the understanding of the role of meteorology on the formation and behavior of air pollutants and their precursors and emission sources and patterns. The information gathered will be used to develop an improved modeling system that will be used in preparing plans to attain the new federal 8-hour ozone standard, as well as to update the Clean Air Plan to attain the state ozone standard.
California Regional Particulate Air Quality Study (CRPAQS)[2]	California	~60	1999 to 2001	PM2.5, PM10, nephelometer, with some sites adding SO4/NO3, OC/EC, NO2, NOy, PAN, SO2, surface meteorology	http://www.arb.ca.gov/airways/	The California Regional PM10/PM2.5 Air Quality Study is a comprehensive public/private sector collaborative program to provide an improved understanding of particulate matter and visibility in central California. It is intended to evaluate both the national and State air quality standards for PM10 and PM2.5. The field programs consisted of 14 months of monitoring throughout the San Joaquin Valley (SJV) and surrounding regions, as well as intensive monitoring during summer, fall, and winter seasonal periods.
Southern Oxidant Study (SOS) 1999 Field Campaign -- Nashville	NOAA	3 sites, 4 aircraft	1999	O3, NO, NO2, NOy, VOCs, aerosols, Surface Meteorology & Upper Air (profiler), ozonesonde -- surface O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters, altitude -- aircraft	http://esrl.noaa.gov/csd/SOS99/	The Southern Oxidants Study (SOS), in collaboration with other organizations and programs, conducted this major Field Campaign during June/July 1999. The Nashville/Middle Tennessee region measurements focused on an improved understanding of the processes that control the formation and distribution of fine particles and ozone. Three study themes were: Local vs. regional contrasts, Ozone and PM formation in plumes, and diurnal cycle in chemistry and meteorology. These themes were addressed through a series of coordinated measurements involving instrumented aircraft and a ground-based network of chemistry and meteorological measurements.

APPENDIX F. FIELD CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES (continued)

PM Supersite Program	EPA	2 Phase I Sites 7 Phase II Sites	1999	Measurement may include: PM2.5, PM10, TSP, SO4, NO3, EC, OC, light absorption & extinction, O3, CO , NOx, NO, NO2, NOy, HNO3, NH3, VOCs, Carbonyls, PAH, major ions and elements, surface and upper air meteorology	http://www.epa.gov/ttn/amtic/supersites.html	In response to Executive and Congressional mandates and recommendations from the National Research Council a "Supersites Conceptual Plan" was developed and implemented. Atlanta and Fresno were selected as initial Phase I sites and as a result of a competitive process Baltimore, Fresno, Houston, Los Angeles, New York, Pittsburgh, and St. Louis were selected for Phase II. Goals generally were to characterize particulate matter, support health effects and exposure research, and conduct methods testing. Extensive monitoring, data analysis, and publication continued to 2005 with the preparation of a Final Report for each city.
Big Bend Regional Aerosol and Visibility Observational (BRAVO) Study	NPS/EPA	38 fixed, 6 tracer sites	1999	SO2, SO4, PM2.5, NO3, NH4, major ions and elements, nephelometer, transmissometer, meteorological parameters & upper air, PFC tracer	http://www.dri.edu/Home/Features/text/BRAVO.htm	The BRAVO study was conducted for four months during 1999 with the primary objective of identifying the causes of haze in the Big Bend National Park located in West Texas. This very large, collaborative study enlisted numerous participants with sponsorship from federal/State agencies, private industry, and research organizations. The BRAVO study utilized data from a 38-site network to characterize spatial and temporal aerosol patterns in the atmosphere. In addition, upper-air measurements and extensive optical measurements of light scattering and absorption were made. Because monitoring and source characterization activities were conducted only in the United States, the study design included additional monitoring and tracer studies along the U.S./Mexican border.
Indian Ocean Experiment (INDOEX)	UCSD	6 sites, 2 ships, 5 aircraft, satellites	1999 (4 months)	O3, NO, NO2, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, trace gases, aerosols, meteorological parameters & upper air	http://data.eol.ucar.edu/codiac/projs?INDOEX	The Indian Ocean Experiment (INDOEX) addresses questions of climate change through collection of in-situ data on the regional cooling effect of sulfate and other aerosols. The project's goal is to study natural and anthropogenic climate forcing by aerosols and feedbacks on regional and global climate. INDOEX field studies occur where pristine air masses from the southern Indian Ocean including Antarctica and not-so-clean air from the Indian subcontinent meet over the tropical Indian Ocean to provide a unique natural laboratory for studying aerosols. Scientists collect data from the water surface through the lower stratosphere, on the aerosol composition, reactive atmospheric gases, solar radiation fluxes, wind and water vapor distribution. To this end, investigators use multiple aircraft, ships and island stations over the Arabian Sea and the Indian Ocean.
Eulerian Model Evaluation Field Study (EMEFS)	Canada	~135	1998	O3, NO2, SO2, NH3, HNO3, major ions,	http://www.msc-smc.ec.gc.ca/natchem/particles/n_emefs_e.html	Under EMEFS, air and precipitation chemistry data were collected daily for two years over much of the eastern United States and Canada to provide data for assessing the performance of acid deposition and other regional scale models.
NARSTO-Northeast 1995	Multiple	559	1995	O3, NO, NOx	http://www.narsto.org/section.src?SID=9	Measurements were made during the NARSTO-Northeast 1995 intensive field campaign during the period May through September. One-hour average O3, NO, and NOX measurement results are reported for ground surface monitoring stations operated by various agencies including EPA AIRS, CASTNet, ESE, Harvard University, NYSEG, PEPCO, and the University of Maryland.

APPENDIX F. FIELD CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES (continued)						
SOS Nashville/Middle Tennessee Ozone Study	TVA	116	1994-1995	O3, SO2, NO, NOy, and CO, VOC, Surface Meteorology, rawinsonde and ozonesonde releases, and a radar profiler/radar acoustic sounding system. -- surface Airborne ozone and aerosol lidar – aircraft	http://www.ncsu.edu/sos/pubs/sos2/State_of_SOS_2.pdf	This ozone-focused field study was carried out in the 11-state region surrounding Nashville/Middle Tennessee, beginning with a 3-week exploratory study during the summer of 1994 and culminating in a six-week field measurement campaign June/July 1995. Measurements were taken at 116 ground-based and tall building and tower-based chemical and meteorological measurement sites and a series of six airborne chemical measurement platforms. The most significant feature of the Nashville/Middle Tennessee Ozone Study was a coordinated series of 40+ aircraft studies to measure physical and chemical characteristics of urban and industrial plumes. (Note: an earlier ozone-focused set of field studies was also conducted in the Atlanta, GA area during the summers of 1990 - 1992.)
North Atlantic Regional Experiment (NARE)	NOAA	various sites, 1 ship	1993, 1996, 1997	O3, NO, NO2, NOx, NOy, VOC, Surface Meteorology	http://www.igac.noaa.gov/newsletter/24/introduction.php	The NARE program measured the type and amount of air pollutants being transported from the North American continent to the Northern Atlantic Ocean. Since the Northeast United States and Nova Scotia, Canada are the last land locations as air masses move out over the ocean, measurements were made a number of land and island sites in Maine, Nova Scotia, and Sable Island. Acadia National Park participated in this study

Footnotes:

1. EPA -- Environmental Protection Agency
   NASA -- National Aeronautics and Space Administration
   NOAA -- National Oceanic and Atmospheric Administration
   NPS -- National Park Service
   NSF -- National Science Foundation
   CARB -- California Air Resources Board
   CEC -- California Energy Commission
   UCSD -- University of California San Diego (Scripts Institution of Oceanography)

2. This study is part of the Central California Air Quality Studies (CCAQS) which comprise the California Regional Particulate Air Quality Study (CRPAQS) and the Central California Ozone Study (CCOS). CCAQS is a multi-year effort of meteorological and air quality monitoring, emission inventory development, data analysis, and air quality simulation modeling. Prior studies in California included: Southern California Ozone Study (SCOS97) -- 1997; Integrated Monitoring Study (IMS95) -- 1995; San Joaquin Valley Air Quality Study (SJVAQS) -- 1990; SARMAP Ozone Study -- 1990; Southern California Air Quality Study (SCAQS) -- 1987.

3. Historically, there have been many other field studies in the 1960's - 1990's that are not reflected in this table that involve both fixed monitoring sites and aircraft; well known examples include Regional Air Pollution Study (RAPS), Large Power Plant Effluent Study (LAPPES), Northeast Corridor Regional Modeling Program (NECRMP), Northeast Regional Oxidant Study (NEROS), Persistent Elevated Pollutant Episode (PEPE), and Lake Michigan Ozone Study (LMOS).

4. In addition to the air monitoring networks and related studies detailed in this table that are primarily concerned with lower tropospheric air pollution, there are a large number of observations and studies conducted by NASA, NOAA and others that address such topics as (1) upper tropospheric and stratospheric ozone and aerosols, (2) cloud processes, and (3) validation experiments for satellite observations. These studies include but are not limited to:
   -- Stratospheric Tropospheric Exchange Project (STEP) – 1987
   -- Airborne Antarctic Ozone Experiment (AAOE) – 1987

-- Airborne Arctic Stratospheric Experiment (AASE) – 1989
-- Airborne Arctic Stratospheric Experiment II (AASE2) – 1992
-- Stratospheric Photochemistry Aerosols and Dynamics Experiment (SPADE) – 1993
-- Airborne Southern Hemisphere Ozone Experiment / Measurements for Assessing the Effects of Stratospheric Aircraft (ASHOE/MAESA) – 1994
-- Stratospheric Tracers of Atmospheric Transport (STRAT) – 1995-1996
-- Tropical Ozone Transport Experiment (TOTE) and Vortex Ozone Transport Experiment (VOTE) – 1995-1996
-- Subsonic Aircraft: Contrail and Clouds Effects Special Study (SUCCESS) – 1996
-- Photochemistry and Ozone Loss in the Arctic Region in Summer (POLARIS) – 1997
-- Subsonic Assessment: Ozone and Nitrogen Oxide Experiment (SONEX) – 1997
-- Texas Florida Underflights A (TEFLUN) – 1998
-- The Third Convection and Moisture Experiment (CAMEX 3) – 1998
-- TRMM Brazil Validation Experiment (TRMM-LBA) – 1999
-- TRMM Kwajalein Validation Experiment (KWAJEX) – 1999
-- Nauru 1999 Field Campaign – 1999
-- South African Fire-Atmosphere Research Initiative 2000 (SAFARI) – 2000
-- SAGE III Ozone Loss and Validation Experiment (SOLVE) – 1999-2000
-- ERAST Predator-B RPV Homepage (ERAST) – 2000
-- CAMEX 4 The Fourth Convection and Moisture Experiment (CAMEX 4) – 2001
-- East Pacific Investigation of Climate (EPIC) 2001 Field Program – 2001
-- The Cirrus Regional Study of Tropical Anvils and Cirrus Layers-Florida Area Cirrus Experiment (CRYSTAL FACE) – 2002
-- The SAGE III Ozone Loss and Validation Experiment (SOLVE II) – 2003
-- The Aura Validation Experiment (AVE) – 2004
-- The Intercontinental Chemical Transport Experiment – North America (INTEX-NA) – 2004
-- The Aura Validation Experiment Houston (AVE Houston) – 2004
-- North American Monsoon Experiment (NAME) – 2004
-- Winter Storms Reconnaissance Program 2004 (WSR2004) – 2004
-- Polar Aura Validation Experiment (PAVE) – 2005
-- The Tropical Cloud Systems and Processes Mission (TCSP) – 2005
-- UAS Flight Demonstration Project 2005 – 2005

APPENDIX G. SATELLITE – BASED AIR QUALITY OBSERVING SYSTEMS[1]						
Instrument	**Satellite Platform[4]**	**Lead Agency**	**Initiated**	**Measurement Parameters[2]**	**Orbit & Horizontal Resolution**	**Location of Information and/or Data**
OLS (Operational Linescan System)	DMSP satellites	DOD	1962?	Identify fires and smoke plumes	Polar Imagery only	http://www.af.mil/factsheets/factsheet.asp?fsID=94
BUV (Backscatter Ultraviolet Spectrometer)	Nimbus 4	NASA	1970-1980	O3, CO2, SO2	Sun synchronous	http://nssdc.gsfc.nasa.gov/database/MasterCatalog?sc=1970-025A
SBUV (Solar Backscatter Ultraviolet Spectrometer)	Nimbus 7	NASA	1978-1993	O3, SO2	Polar	http://jwocky.gsfc.nasa.gov/n7toms/nimbus7tech.html
TOMS (Total Ozone Mapping Spectrometer)	Nimbus 7 Meteor 3 Earth-Probe	NASA	1978-1993 1991-1994 1996-2005	O3, SO2, Aerosols	Polar ~100km^2	http://toms.gsfc.nasa.gov/fltmodel/spacecr.html
LIMS (Limb Infrared Monitor of the Stratosphere)	Nimbus 7	NASA	1978-1979	O3, HNO3, NO2,	Polar	http://toms.gsfc.nasa.gov/n7toms/nimbus7tech.html
ATMOS (Atmospheric Trace Molecule Spectroscopy)	Spacelab 3 ATLAS -- 1,2,3	NASA	1985, 1992, 1993, 1994	O3, CFCl3, CF2Cl2, ClONO2, HCl, HF, CO, CH4, HCN, HNO3, NO, NO2, N2O, N2O5, Aerosols		http://remus.jpl.nasa.gov/atmos/sl3.html
CLAES (Cryogenic Limb Array Etalon Spectrometer)	UARS	NASA	1991-1993	O3, CFCl3, CF2Cl2 ClONO2, CH4, HNO3, NO, NO2, N2O, N2O5, Aerosols		http://umpgal.gsfc.nasa.gov/
HALOE (Halogen Occultation Experiment)	UARS	NASA	1991-2005	O3, HCl, HF, CH4, NO, NO2, Aerosols		http://umpgal.gsfc.nasa.gov/
ISAMS (Improved Stratospheric and Mesospheric Sounder)	UARS	NASA	1991-1992	O3, CO, CH4, NO2, N2O, N2O5, Aerosols		http://umpgal.gsfc.nasa.gov/
MLS (Microwave Limb Sounder)	UARS	NASA	1991-1999	O3, ClO, CH3CN, HNO3, SO2		http://umpgal.gsfc.nasa.gov/
GOES Imager (Geostationary Operational Environmental Satellites)	GOES-10 GOES-12	NOAA	1994	Fire products for WF_ABBA (imagery) and GASP (aerosol optical depth)	Geostationary 4x4 km^2	http://www.nesdis.noaa.gov/sat-products.html
GOES Sounder (Geostationary Operational Environmental Satellites)	GOES-10 GOES-12	NOAA	1994	Total column O3	Geostationary	http://cimss.ssec.wisc.edu/goes/data.html
AVHRR[3] (Advanced Very High Resolution Radiometer)	NOAA-15 NOAA-16 NOAA-17 NOAA-18	NOAA	1998	Aerosol optical depth, particle size information and vegetation/drought index products related to air quality through fires	Polar ~1x1 km^2	http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html
SBUV/2[3] (Solar Backscattered Ultraviolet Radiometer Model 2)	NOAA-16 NOAA-17 NOAA-18	NOAA	2000	Total and profile O3 from surface to top of atmosphere in ~5 km thick Umkehr layers	Polar	http://www.ozonelayer.noaa.gov/action/sbuv2.htm

APPENDIX G. SATELLITE – BASED AIR QUALITY OBSERVING SYSTEMS[1] (continued)

MOPITT (Measurement of Pollution in the Troposphere)	EOS Terra	NASA	1999	CO, CH4	Polar 22 x 22 km^2	http://www.eos.ucar.edu/mopitt/
MISR (Multi-angle Imaging SpectroRadiomenter)	EOS Terra	NASA	1999	Aerosol properties and plume height information near the vicinity of fires	Polar ~1x1 km^2	http://www-misr.jpl.nasa.gov/mission/introduction/welcome.html
MODIS (Moderate Resolution Imaging Spectroradiometer)	EOS Terra EOS Aqua[5]	NASA	1999 2002	O3, Aerosol optical depth, particle size information, fine particle fraction, and forest fires	Polar ~1x1 km^2	http://modarch.gsfc.nasa.gov/index.php
AIRS (Atmospheric Infrared Sounder)	EOS Aqua[5]	NASA	2002	Total column ozone, surface temperature, temperature and moisture vertical profiles, (plus under development are CO and CO2 total column, O3 vertical distribution, and CH4 distribution)	Polar 50km	http://airs.jpl.nasa.gov/
HIRDLS (High Resolution Dynamics Limb Sounder)	EOS Aura[5]	NASA	2004	O3, CFC11, CFC12, ClONO2, CH4, HNO3, NO2, N2O, N2O5, Aerosols	Polar	http://aura.gsfc.nasa.gov/index.html http://www.nasa.gov/mission_pages/aura/spacecraft/index.html
MLS (Microwave Limb Sounder)	EOS Aura[5]	NASA	2004	O3, BrO, ClO, HOCl, HCl, CO, HCN, CH3CN, HNO3, N2O, OH, HO2	Polar	http://aura.gsfc.nasa.gov/index.html http://www.nasa.gov/mission_pages/aura/spacecraft/index.html
OMI (Ozone Monitoring Instrument)	EOS Aura[5]	NASA	2004	O3, BrO, OClO, HCHO, NO2, SO2 and aerosols	Polar 48 x 48 km^2	http://aura.gsfc.nasa.gov/index.html http://www.nasa.gov/mission_pages/aura/spacecraft/index.html
TES (Total Emission Spectrometer)	EOS Aura[5]	NASA	2004	O3, CO, CH4, HNO3	Polar 26 x 42 km^2	http://aura.gsfc.nasa.gov/index.html http://www.nasa.gov/mission_pages/aura/spacecraft/index.html
CALIPSO (Cloud-Aerosol Lidar & Infrared Pathfinder Satellite Observations)	CALIPSO[5]	NASA	2005	Aerosol optical depth, backscatter, extinction	Polar 0.3 x 0.3 km^2	http://www-calipso.larc.nasa.gov/about/
OMPS (Ozone Mapping and Profiling Suite)	NPOESS - Preparatory Project	NOAA	To be launched 2010	Total column and vertical profile ozone data	Polar	http://www.ipo.noaa.gov/index.php?pg=proj
VIIRS (Visible Infrared Imaging Radiometer Suite)	NPOESS - Preparatory Project	NOAA	To be launched 2010	Aerosol optical depth	Polar	http://www.ipo.noaa.gov/index.php?pg=proj
Orbiting Carbon Observatory	OCO[5]	NASA	2009 (failed)	CO2	Polar	http://oco.jpl.nasa.gov/
APS & TIM (Aerosol Polarimetry Sensor & Total Irradiance Monitor)	Glory	NASA	2009 (planned)	Black carbon soot, other aerosols, total solar irradiance, cloud images	Sun- synchronous, circular, Low Earth Orbit	http://glory.gsfc.nasa.gov/

APPENDIX G. SATELLITE – BASED AIR QUALITY OBSERVING SYSTEMS[1] (continued)

SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Chartography)	Envisat	ESA	2002	Total column for O3, NO2, BrO, OClO, SO2, HCHO, aerosols	Polar 60 x 30 km^2	http://envisat.esa.int/instruments/sciamachy/
GOME & GOME-2 (Global Ozone Monitoring Experiment)	ERS-2 MetOp-A	ESA	1995 2006	Total column for O3, NO2, BrO, SO2, HCHO, aerosols	Polar 40 x 40 km^2	http://earth.esa.int/ers/gome/ http://www.esa.int/esaLP/SEMTTEG23IE_LPmetop_0.html
IASI (Infrared Atmospheric Sounding Interferometer)	MetOp-A	ESA	2006	O3, CO, CH4	Polar 50 x 50 km^2	http://smsc.cnes.fr/IASI/index.htm

Footnotes:
1. Some instrument systems listed (e.g., UARS/HALOE) are oriented primarily to stratospheric measurements and may have limited application to the troposphere.
2. Note that many of the satellite instruments also have the capability to measure temperature, H_2O and other parameters.
3. NOAA satellites as early as 1978 have carried AVHRR, and as early as 1985 have carried BUV/2
4. CALIPSO -- Cloud-Aerosol Lidar & Infrared Pathfinder Satellite Observations
   DMSP -- Defense Meteorological Satellite Program
   EOS -- Earth Observing System
   ESA -- European Space Agency
   GOES -- Geostationary Operational Environmental Satellites
   NASA -- National Aeronautics and Space Administration
   NOAA -- National Oceanic and Atmospheric Administration
   NPOESS -- National Polar-orbiting Operational Environmental Satellite System
   OCO -- Orbiting Carbon Observatory
   UARS -- Upper Atmosphere Research Satellite
5. This satellite is part of the A-Train group of satellites. It will involve for the first time satellites flying in a formation that crosses the equator one satellite at a time, a few minutes apart, at around 1:30 pm local time. The A-Train is made up of Aqua, Aura, CALIPSO, and will include Glory in 2009; it also includes CloudSat (2005) – data on the structure of ice and water clouds, and PARASOL (2004) – data on the directional characteristics and polarization of light reflected by the Earth and atmosphere, including aerosol optical depth. Together their overlapping science instruments will give a comprehensive picture of Earth weather and climate.

APPENDIX H.
AIR MONITORING NETWORKS FOR CLIMATE FORCING, TRANSPORT, VERTICAL PROFILE INFORMATION, AND STRATOSPHERIC OZONE

Network	Lead Federal Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
Global Monitoring Division Baseline Observatories					
Mauna Loa	NOAA	1	1957	CO2, CO, CH4, SO2, O3, SF6, N2O, H2, CFCs, HCFCs, HFC's, Aerosols, Solar Radiation, Surface Meteorology	http://www.cmdl.noaa.gov/obop/mlo/
Point Barrow	NOAA	1	1973	CO2, CO, CH4, SO2, O3, SF6, N2O, H2, CFCs, HCFCs, HFC's, Aerosols, Solar Radiation, Surface Meteorology	http://www.cmdl.noaa.gov/obop/brw/
Samoa	NOAA	1	1974	CO2, CO, CH4, SO2, O3, SF6, N2O, H2, CFCs, HCFCs, HFC's, Aerosols, Solar Radiation, Surface Meteorology	http://www.cmdl.noaa.gov/obop/smo/
South Pole	NOAA	1	1957	CO2, CO, CH4, SO2, O3, SF6, N2O, H2, CFCs, HCFCs, HFC's, Aerosols, Solar Radiation, Surface Meteorology	http://www.cmdl.noaa.gov/obop/spo/
Trinidad Head	NOAA	1	2002	CO2, CO, CH4, SO2, O3, SF6, N2O, H2, CFCs, HCFCs, HFC's, Aerosols, Solar Radiation, Surface Meteorology	http://www.cmdl.noaa.gov/obop/thd/
Global Monitoring Division -- Carbon Cycle Greenhouse Gases Group (CCGG)					
Observatory Measurements	NOAA	4	1957	See above baseline observatories	http://www.cmdl.noaa.gov/ccgg/insitu.html
Cooperative fixed sites	NOAA	62	1967	CO2, CH4, CO, H2, N2O, and SF6, stable isotopes of CO2 and CH4	http://www.cmdl.noaa.gov/ccgg/flask.html
Commercial Ships	?????	?????	?????		
University of Washington					
Cheeka Peak Observatory	None	1	1997	O3, CO, Aerosols, Solar Radiation, Surface Meteorology	http://www.washington.edu/research/field/
Mt. Bachelor Observatory	None	1	2004	O3, CO, NO/NO2, Aerosols, Hg, Surface Meteorology	http://research.uwb.edu/jaffegroup/modules/mbo_plot/
Vertical Profile and Other Measurement Networks					
ALE / GAGE / AGAGE Network	NASA	5 Current 2 Discontinued	1978	CO, CH4, SF6, N2O, H2, CFCs, HCFCs, HFC's, methyl chloroform, carbon tetrachloride, chloroform, perchloroethylene, halons & others	http://cdiac.ornl.gov/ndps/alegage.html
Tall Tower Measurements	NOAA	8	1992	CO2, CO, CH4, H2, CFCs, methyl chloroform, carbon tetrachloride, chloroform, sulfur hexafluoride, perchloroethylene	http://www.esrl.noaa.gov/gmd/ccgg/towers/index.html http://www.nacarbon.org/cgi-nacp/web/investigations/inv_pgp.pl?pgid=171
Research Wind Profiler Network	NOAA	variable	???	Vertical wind and temperature profiles, surface meteorology	http://www.etl.noaa.gov/et7/data/
REALM – Regional East Atmospheric Lidar Mesonet	NOAA	13	2004	Lidar measurements for mixing height and vertical profiling of aerosols, ozone and water vapor	http://alg.umbc.edu/REALM/
Ozonesonde Network	NOAA	3 (9?)	???	Weekly Upper Air measurements of ozone, temperature, and humidity information from surface to approximately 32 km	http://www.cmdl.noaa.gov/ozwv/ozsondes/
SHADOZ Network (Southern Hemisphere ADditional Ozonesondes)	NASA	12	1998	Upper air measurements of ozone, temperature, and humidity	http://croc.gsfc.nasa.gov/shadoz/

APPENDIX H.
AIR MONITORING NETWORKS FOR CLIMATE FORCING, TRANSPORT, VERTICAL PROFILE INFORMATION, AND STRATOSPHERIC OZONE (continued)

Aircraft Measurements	NOAA	16 airport sites	1992	CO_2, CH_4, N_2O, CO, H_2, SF_6	http://www.cmdl.noaa.gov/ccgg/aircraft.html http://www.nacarbon.org/cgi-nacp/web/investigations/inv_pgp.pl?pgid=171
Networks for Halogenated Gases and Ozone	NOAA	Multiple platforms	1986	nitrous oxide (N_2O), CFCs, HCFCs, HFCs, CH_3Br, CH_3Cl, CH_3I), halons	http://www.cmdl.noaa.gov/hats/
Network for Aerosols	NOAA	Multiple platforms	mid-1970s	light absorption, total scattering and backscattering	http://www.cmdl.noaa.gov/aero/
Ameriflux CO2 exchange network	DOE, NOAA, USDA, NASA	~50 Micrometerological towers	1996	CO_2, meteorological variables	http://public.ornl.gov/ameriflux/index.html
FluxNet CO2 exchange network	International	~150 Micrometerological towers	1996	CO_2, meteorological variables	http://www.fluxnet.ornl.gov/fluxnet/index.cfm
North American Carbon Program Atmospheric Observing System	Multiple participants	Multiple platforms	2001	CO, CO_2, CH_4	http://www.nacarbon.org/nacp/
AERONET -- AErosol RObotic NETwork MPLNET – Micro-pulse Lidar Network	NASA co-located networks	22 + other participants 8	1998 2000	Aerosol spectral optical depths, aerosol size distributions, and precipitable water Aerosols and cloud layer heights	http://aeronet.gsfc.nasa.gov/index.html http://mplnet.gsfc.nasa.gov/
International Aircraft Measurements					
MOZAIC (Measurement of ozone, water vapour, carbon monoxide and nitrogen oxides aboard Airbus in-service aircraft)	None	2500 Airbus international flights/year	1994	O_3, H_2O, CO, NO_x	http://www.fz-juelich.de/icg/icg-ii/mozaic/home
NOXAR (Measurements of Nitrogen Oxides and Ozone Along Air Routes)	None	500 Swiss Air flights to U.S. and far east	1995 - 1996	O_3, NO, NO_2	http://www.iac.ethz.ch/en/research/chemie/tpeter/Noxar.html
CARIBIC (Civil Aircraft for the Regular Investigation of the atmosphere Based on an Instrument Container)	None	~100 Lufthansa flights	1997	CO, O_3, CO, CH_4, CO_2, N_2O, SF_6, NMHC, Position & Meteorology and Cloud cover.	http://www.caribic-atmospheric.com/
AMATRAS (Atmospheric Measurement by Airliners for Trace Species)	None	262 flights between Japan and Australia	1993	CO_2, CH_4, CO and SF_6	http://www.jal.com/en/press/0000336/img/AMATRAS.pdf
NOAA Research Observing Systems (Systems typically incorporated in intensive field campaigns)					
R/V Ronald H. Brown, Lockheed WP-3D Twin Otter	NOAA	ship aircraft aircraft	???	O_3, NO, NO_2, NO_y, VOCs, CO_2, CO, SO_2, HNO_3, NH_3, other reactive pollutants, aerosols, meteorological parameters & upper air, altitude	http://esrl.noaa.gov/csd/2006/p3science.html

Appendix I. Acronyms

Monitoring-Related Terminology
AOD – Aerosol Optical Depth
AQI – Air Quality Index
AQS – Air Quality System
CAA – Clean Air Act
CFR – Code of Federal Regulations
CMAQ – Community Multiscale Air Quality Model
CTM – Chemical Transport Model
FEM – Federal Equivalent Method
FDDA – Four-Dimensional Data Assimilation
FRM – Federal Reference Method
FTIR – Fourier transform infrared spectroscopy
GHG – Greenhouse Gas
HAPs – Hazardous Air Pollutants
LIDAR – LIght Detection And Ranging
NAAMS – National Ambient Air Monitoring Strategy
NAAQS – National Ambient Air Quality Standards
NATA – National Air Toxics Assessment
NMOC – Non-Methane Organic Carbon
PBL – Planetary Boundary Layer
POP – Persistent Organic Pollutant
RASS – Radio-Acoustic Sounding System
SIP – State Implementation Plan
VOC – Volatile Organic Compound

Government Agencies and Sponsored Organizations
AQRS – Air Quality Research Subcommittee (CENR)
CENR – Committee on Environment and Natural Resources
CEQ – Council on Environmental Quality
DOE – Department of Energy
DOI – Department of the Interior
EPA – Environmental Protection Agency
ESA – European Space Agency
GEO – Group on Earth Observations
GMES – Global Monitoring for Environment and Security
HEI – Health Effects Institute
IGAC – International Global Atmospheric Chemistry Project
NACP – North American Carbon Program
NARSTO – North American Research Strategy for Tropospheric Ozone
NAS – National Academy of Sciences
NASA – National Aeronautics and Space Administration
NOAA – National Oceanic and Atmospheric Administration
NPS – National Park Service
NRC – National Research Council

NWS – National Weather Service
OSTP – Office of Science & Technology Policy
USGEO – United States Group on Earth Observations
USDA – United States Department of Agriculture
USGS – United States Geological Survey
WMO – World Meteorological Organization

Monitoring Networks
AERONET – AErosol Robotic NETwork
AGAGE – Advanced Global Atmospheric Gases Experiment
AIRMoN – Atmospheric Integrated Research Monitoring Network
ALE – Atmospheric Lifetime Experiment
AMNET – Atmospheric Mercury Network (NADP)
ASOS – Automated Surface Observing System (NOAA)
BSRN – Baseline Surface Radiation Network
CARIBIC – Civil Aircraft for Regular Investigation of the atmosphere Based on an Instrument Container
CASTNET – Clean Air Status and Trends Network
CSN – Chemical Speciation Network
GAGE – Global Atmospheric Gases Experiment
GALION – GAW Atmospheric LIdar Observation Network
GAW – Global Atmospheric Watch
GEMS – Global and regional Earth-system (Atmosphere) Monitoring using Satellite and in-situ data
GEOSS – Global Earth Observation System of Systems
IADN – Integrated Atmospheric Deposition Network
IGACO – Integrated Global Atmospheric Chemistry Observations
IMPROVE – Interagency Monitoring of Protected Visual Environments
MACC – Monitoring Atmospheric Composition and Climate
MADIS – Meteorological Data Ingest System
MDN – Mercury Deposition Network
MOZAIC – Measurement of OZone, water vapor, carbon monoxide and nitrogen oxides aboard in-service AIrbus aircraft
MPLNET – Micro Pulse Lidar Network
NADP – National Atmospheric Deposition Program (NADP)
NATTS – National Air Toxics Trends Stations
NCore – National Core Network
NDACC – Network for the Detection of Atmospheric Composition Change
NEUBREW – NOAA-EPA Brewer Spectrophotometer UV and Ozone Network
NPN – NOAA Profiler Network
NTN – National Trends Network (NADP)
PAMS – Photochemical Assessment Monitoring Stations
SEARCH – SouthEastern Aerosol Research and Characterization Study
REALM – Regional East Atmospheric Lidar Mesonet
SIRD – Supersites Integrated Relational Database

SLAMS – State and Local Air Monitoring System
SOS – Southern Oxidants Study
STN – Speciation Trends Network
SURFRAD – SURFace RADiation budget observing network
TAMDAR – Tropospheric Airborne Meteorological Data Reporting
VIEWS – Visibility Information Exchange Web System
UATMP – Urban Air Toxics Monitoring Program

Intensive Field Campaigns
ARCTAS – Arctic Research of the Composition of the Troposphere from Aircraft and Satellites
AUSPEX – Atmospheric Utility Signatures, Predictions and Experiments
EMEFS – Eulerian model evaluation field study
HTAP – Hemispheric Transport of Air Pollution
ICARTT – International Consortium for Atmospheric Research on Transport and Transformation
INTEX-NA – Intercontinental Chemical Transport Experiment North America
INTEX-B – Intercontinental Chemical Transport Experiment Phase B
ITCT – Intercontinental Transport and Chemical Transformation
MILAGRO – Megacity Initiative: Local and Global Research Observations
NARE – North American Regional Experiment
NEAQS - ITCT 2004 – New England Air Quality Study - Intercontinental Transport and Chemical Transformation
POLARCAT – Polar Study using Aircraft, Remote Sensing, Surface Measurements and Models, of Climate Chemistry, Aerosols, and Transport
RAPS – Regional Air Pollution Study
SJVAQS – San Joaquin Valley Air Quality Study
TexAQS – Texas Air Quality Study
TRACE-P – Transport and Chemical Evolution over the Pacific

Satellite-Oriented Programs, Systems & Terms
ACE – Aerosol-Cloud-Ecosystems mission
EOS – Earth Orbiting System
CALIPSO – Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation satellite
GEO – Geostationary satellite platform
GEO-CAPE – Geostationary Coastal and Air Pollution Events
GACM – Global Atmospheric Composition Mission
GOES – Geostationary Operational Environmental Satellites
GOME – Global Ozone Monitoring Experiment
GOSAT – Greenhouse gases Observing SATellite
LEO – Low Earth Orbit
MODIS – Moderate Resolution Imaging Spectroradiometer
MOPITT – Measurements of Pollution in the Troposphere
NESDIS – National Environmental Satellite, Data, and Information Service (NOAA)
NPOESS – National Polar-orbiting Operational Environmental Satellite System
NPP – NPOESS Preparatory Project

OCO – Orbiting Carbon Observatory
OMI – Ozone Monitoring Instrument
PARASOL – Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar
POES – Polar Operational Environmental Satellite
PROMOTE – PROtocol MOniToring for the GMES Service Element: Atmosphere
SCIAMACHY – SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY
TOMS – Total Ozone Mapping Spectrometer
TOR – Tropospheric Ozone Residual